Parallel Generators Implementation to Control Load Changes Operation at Offshore Platform

1st Agus Sofwan
Electrical Department,
National Institute of Science and Technology, Jakarta, Indonesia,
asofwan@istn.ac.id

2nd Sugeng
Electrical Department
UNISMA,
Bekasi, Indonesia,
sugengpratama1975@gmail.com

3rd M.Lufi Hasim
Operation Department,
PT. PHEONWJ, ,
Jakarta, Indonesia
luthfi.ihsanan@gmail.com

***Abstract*—.The Service and Compressor Offshore Platform operation in the Java North of is served by two separate and non-parallel power plants, but their utilization isn't optimal. This is due to a load imbalance, where one power plant is overloaded, but on the other hand, power plant has a little load. To increase offshore oil production, it is necessary to add the platform load. However, load increasing will not be possible if the system is unmodified. On that basis, it is necessary to provide an optimal power generator service solution without having to add new transformers. In this study, parallel system implementation of two power plants will be analyzed in order to serve the load change. Thus, it is hoped that a new modification of the power plant will be formed so that product improvement can be achieved. As the development plan, the "SERVICE" platform with a capacity of 1000kW must provide a load of 133.84% while the compressor platform generator capacity with a capacity of 750kW only serves a load of 50.88%. After implementing the paralleling system of the two generators, the total power that can be generated is 1750kW and will serve a load of 1720kW (98.28%). For the implementation of the new system should be analyzed in parallel feeder capability to the maximum short circuit current. Based on the p u-calculation that the main bus bar Rating is 50kA and branch bus bar rating is 25kA, whereas the maximum short circuit current is only 24.150kA. Thus, the platform feeder ability is still above the maximum short circuit current. Finally, in principle, the plant was able to serve the load changes, but the situation is critical due to the imposition of above normal conditions. For that the operation of such arrangements are ideally required load shedding.**

Keywords— ***Parallel Generator, Load shedding system, Short circuit, Overload, Per-unit method calculation and Platform.***

I. Introduction

On the northern island of Java there are many oil wells. Oil wells are divided into several areas, where each area is an oil rig. Oil rigs typically consist of four platforms, namely the service platform, the platform wells, platforms and platform process compressors. Each platform is a length of approximately 25 meters and connected by a bridge to serve as a channel for distribution stations. On the platform of the process, crude oil is separated from the gas and water in the tank separator as a separator production, where crude oil is pumped to a separate reservoir. Gas supplied to the compressor platform and then used to increase the pressure. Some of the gas is channeled directly to consumers via distribution pipes to supply fuel for the Steam-Gas Power Plant, some is sold to fertilizer factories, some is reprocessed as lifting gas for petroleum and fuel for turbine gas compressors on the platforms themselves and gas engines for generator set. This oil and gas processing requires considerable electrical power. To fulfill it, this electric power is obtained from a generator using a gas engine and a diesel engine. The resulting voltage is 480 V_{AC} with a frequency of 60 Hz. The imbalance between load power and generation can affect the frequency increase [1].

On this platform the power plant is placed on the service platform and compressor platform. Because of its position offshore, it is necessary to optimize the operation of the generator. In obtaining the optimization of the generation power, many studies have been carried out such as research on leakage currents in loads, generator operating methods and parallel work of several generators [1] [2]. Some Various previous methods are used in optimal processes in thermal power plants operations, including Particle Swam Optimizing (PSO), BAT Method and Lagrange method [3].

This research was conducted at offshore LIMA in the north of Java Island, where there are 2 platforms, namely the service platform and the compressor platform. At the service platform, the electric power is used to drive the electric motor driving the water pump, oil pump, air compressor for control of wind power, fresh water maker, air conditioning, lighting and electricity for residential facilities. At compressor platform, most of the electric power used for an auxiliary motor in the gas turbine compressor, including cooling fans, lubricating oil pumps, engine starter, fuel pump, and battery chargers. The ratio of the existing load on Compressor Platform reached 47.16%, while in the service platform is only 16.4%.

Due to consumer demand for needs of oil and gas increases, the capacity of processing of oil and gas will also increase. For this reason, it is necessary to increase platform production. In order to increase production, of course, additional equipment that requires large electrical power is needed. If the condition of power plant configurations available are not changed, plans to increase production cannot be realized. In power optimization in the PV system with multiple parallel pumps has analyzed [4]. Likewise, this platform operation requires power optimization.

The existing power plant system must meet the demand for energy in order to increase production. The problem is how the addition of a new power load can be overcome with the existing plant, without the addition of a new power plant. For this reason, an optimal solution is needed to realize increased platform production without the addition of new plant. So, on this offshore must be planned to increase platform production. A parallel system implementation on 2 platforms as an optimal solution without addition of new plant for increased production. To that end, the chosen implementation of parallel systems works on both the power plant for a total capacity of power provided they meet the necessary power requirements. So, the optimal solution is used, which parallels the 2 power plants.

II. GENERAL DEFINITIONS

To supply power to serve the maximum load, two or more generators must be parallelized to increase the amount of power generated. In addition to the parallel work is also often required to maintain continuity of supply of electricity if no power plant is to be stopped for the repair and maintenance program. In addition, load shedding systems can also be applied. For implement of parallel system, must meet the requirements, namely: Voltage and frequency must be equal to bus. In addition, the phase difference or phase angle must also be same for both generators and the phase order of two generators must be the same. Configuration comparison of multiple generators in series and parallel reported [5]. Island operation of more parallel generators connected to one Grid Substation has been developed [6].

To get same voltage, automatic equipment is needed to maintain the stability of the generator output voltage. The tool is called AVR (Automatic Voltage Regulator). During the work the system in parallel the same voltage must be maintained. Because if there is a difference in the generator output voltage it will damage the equipment system. Meanwhile, to get the same frequency between the bus and generator, it is necessary to adjust the generator rotational speed. Automatic Speed Controller (ASR) is a device that is needed to keep the drive rotation speed, so that the frequency of the generator can be maintained equal to the frequency of the bus or with another generator. The frequency curve can be seen on the frequency meter. The phase angle between the generator and the system must also be same. Similarly, to equalize genset phase angle should also be regulated, namely by adjusting the speed of the generator. Meanwhile, to see same phase sequence of the two generators, a synchronization lamp is needed. If all the above conditions are met, then it can be said to be synchronous generator and can be parallelized.

In Fig.1, a block diagram of generator system is clearly shown, for single or parallel operation. The prime mover starts moving the generator which is controlled by the governor. The amount of generation depends on the generated excitation voltage, which is controlled by the voltage regulator. The output voltage from this generator will go through the control cabinet and then go to the load side.

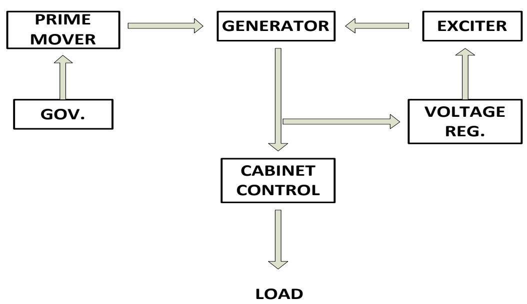

Figure 1. Block Diagram on Generator system

In Table 1, it can be seen that the load data conditions that exist before and after the application of parallel generator operations. Table 1 shows the existing load that must be served from each generator from the two platforms. In the initial conditions the Power capacity of the Platform Compressor of 810kW only has a load of 47.16%, while the Platform Service with a capacity of 1000kW only has a load of 16.35%. To increase platform production, it is of course, necessary to add equipment to the service platform which requires 1174.5kW of power or 133.8%. This of course would not be possible without the addition of a new generator. For this reason, it is necessary to find an optimal solution, namely by implementing parallel work of the two existing generators.

Table 1. Existing load data on two platforms

Platform	Compressor	Service	Condition
Power Cap (KW)	750/810	750/1000	Before Parallel Operation
Exist Load (kW)	382	163.5	
Add Load (kW)	0	1174.5	
Total Load %	47.16	133.8	
Power Cap.(KW)	1810		After Parallel Operation
New Load	382	1338	
Total Load (kW)	1720		
Load %	95.03		

In parallel system it is found that the total power capacity is 1810kW and planned total new load is 1720kW or 95.03%. This illustrates that the power generated is still able to serve new total load, but the condition is critical because generally the load service operation of generator normally ranges from 80%. Therefore, in Generator operation required combination system with the load shedding implementation.

II.1. Synchronization of Three Phase Generator

The synchronization process for a three-phase generator, only one phase needs to be synchronized, while the other two phases will be synchronized automatically [7]. To realize this generator synchronization process, 3 indicator lights are used as shown in Fig. 2.[8].

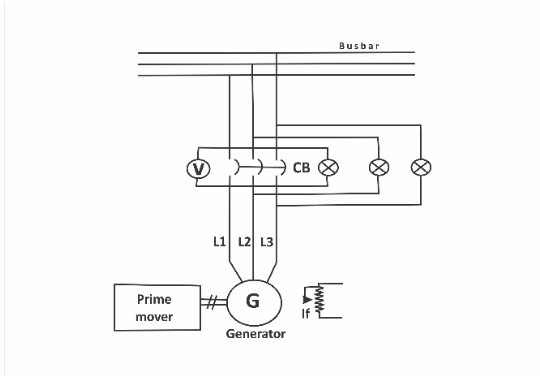

Figure 2. Three phase synchronization circuit.

In Fig. 2 Generator will be paralleled with a bus bar. At first generator G is driven by the prime mover to approach the synchronous rotation, and if it has not reached Synchrony it can be done excitation until the generator voltage equal to the voltage bus bar. To detect the frequency and phase sequence voltage service (generator and bus bar) is used in the form of light detection. If the parallel circuit is correct then the lamps will remain off. If the light is not blinking, the network voltage frequency equal to the frequency of the generator ($f_L = f_G$). In this case, the frequency generator is set by the prime movers, while the voltage is controlled by the excitation [9].

Conversely, if the parallel generator circuit is wrong or the phase sequence is out of sync, the indicator lights will turn on and off alternately with the cycle frequency $f_L + f_G$. As a simulation, the two phases at the generator terminals have to be exchanged for the order [10] [11]. For more details, see Figure 2. L1 L2 L3 is the bus bar phase sequence according to the phase voltage generator sequence. In the analysis of the application of parallel work, it is necessary to calculate the maximum asymmetric current that is likely to occur and will be burdened on the existing feeder. In calculating the fault current, the system per unit (p. u) calculation will be used. In this system used four base values are: kVA Base, Voltage Base, Current Base and Impedance Base. Usually S Base (kVA) is used as a reference by using easy and integer numbers. The relationship between each of the base unit and the actual value expressed in the following equation: [12].

$$\text{Per Unit} = \frac{\text{Real Value}}{\text{Base Value}} \quad \text{So,} \quad I_{Base} = \frac{\text{S Base (kVA) x } 10^3}{\sqrt{3}\text{ V Base}},$$

$$Z_{Base} = \frac{\text{VL−L Base}}{\sqrt{3}\text{ I Base}} = \frac{(\text{V Base})^2}{\text{S Base (kVA) x } 10^3}$$

$$\text{So,} \quad Z_{pu} = \frac{\text{Z Real x (S Base (kVA))}}{(\text{S Basis (kVA)})^2 \text{ x } 10^3}$$

The next step is to determine the reactance and resistance parameters in units per unit (p.u) on the equipment connected in the distribution line such as generators, transformers, motors, cables and breakers. Then all reactance X per unit is calculated as well as all resistances R per unit to give X per total unit and total R per unit to get the total impedance Z in p u. Symmetrical short-circuit current calculation as follows [13].

$$I_{SC} = \frac{\text{S Base (kVA)}}{\sqrt{3} \text{ x } KV_{LL} \text{ x Zper unit total}}$$

$$\text{Calculation of X / R ratio is:} \quad \text{Ratio} = \frac{\text{Xper unit total}}{\text{Rper unit total}}$$

In Table 2 can be seen the obtained asymmetrical factor for the ratio X/R [19][20]. Furthermore, it can be calculated asymmetric short circuit current, namely:

$$I_{Sc} = I_{SC\ symmetrical} \text{ x asymmetric factor}$$

Table 2. Main load data on Service platforms [17]

Existing Load	Amount (Unit)	Rating	Z (%)	Ratio X/R
Transformer 480/120V	1	75kVA	3,5	3.25
Transformer 480/120V	1	150kVA	4,0	3.23
Motor of Air Comp.	2	50Hp	-	-
Motor Fan of Cooler	2	2 Hp		
Fuel pump motor	1	1 Hp		
Oil pump motor	5	125Hp		
HVAC Living Quarters	-	83kVA		

The main equipment and loads to be served on the service platform can be seen in table 2, while the load capacity on the compressor platform is presented in Table 3.

Tabel 3. Main load data on Compressor platforms [18]

Existing Load	**Amount (Unit)**	**Rating**	**Z (%)**	**Ratio X/R**
Transformer 480/120V	2	45kVA	3.0	3.00
Transformer 480/120V	1	30kVA	3.0	3.0
Motor of Air Compressor	2	30Hp	-	-
Fan Motor of Cooler	2	2 Hp		
Pump Motor of Cooling water	1	40 Hp		
Jockey pump Motor	1	25Hp		
Fan Motor of Gas Cooling	4	50 Hp		
Air Circulation FAN Motor	4	1.5 Hp		
Fan Motor of Turbine Enclosure	2	5.0 Hp		
Fan Motor of Turbine Enclosure	2	3.0 Hp		
Fan Motor of Gas Intake	2	1.5 Hp		

II.2. Power Generator Data and Load Shedding

On the Service platform, there are 4 generator units, each with a capacity of 250kW, where 3 x 250 kW as the main generator and 1 x 250 kW as a backup generator. Currently, three generator units that operate with total generated power of 750 kW is planned to serve new load installed on this platform amounted to 958.73 kVA [19]. This is problematic because the load exceeds 100% of capacity.

On this compressor platform has 3 generating units with a capacity of 3 x 250 kW as the main generator and 1 x 60 kW as a backup generator. Currently, three genset units operate with a total power generated of 750 kW with a total installed load of 524.51 kVA or only 64.75% loading. To overcome the problem of load imbalance, then chosen an optimal solution in the form implemntasi parallel work of power systems both platforms. With the implementation of a parallel generator system, the expected total power ratio can be increased.

By parallelizing the generator between the generator on the Compressor and Service platforms, a load shedding system is still needed for operation because the loading factor of power plant system is above 80%. This is done especially when the power plant is operating at full capacity. This load shedding is done to anticipate if one of the power plants does not operate, of course, the stability of the Power plant system will be disturbed. This load shedding system can help the system quickly systematically so that the system can operate normally. This is intended to maintain stability and increase the reliability of electric power system [20].

At full load, the service platform requires 1338 kVA of power, but because only two oil pump motors are operating, the power required is only about 968 kVA. While the compressor platform in full load conditions requires a power of 524.5 kVA. So the total power required is 1492.5 kVA (when viewed from the rating of each load), but in reality the total power required is 1082.95 kVA.

When one or more generators off, the load shedding control system will empower part of the load that is being operated. Load shedding is used to get the non operated load. This is so that the system can operate normally. Table 4 shows the paralell parameters, there are Voltage, Frequency and Power factor of System as required data [19].

Table 4: Data Generator of Platform Services and Compressors

Service and Compressor Platform	
Operator	250 Kw
Voltage	480 Volt / 3 Phase
Frequency	60 Hz
Power Factor	0.8

The one-line diagram of the two platforms can be seen in Figure 3 below as bridge Service.

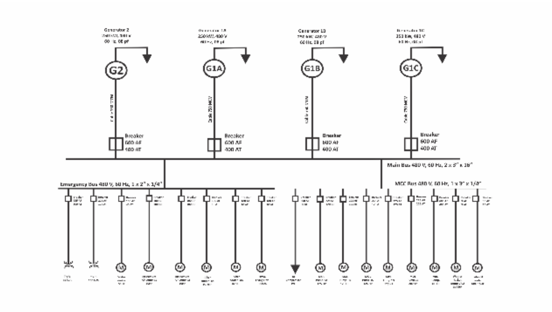

Figure 3. Installation Diagram of Platform

Load requirement is addition electric motors that require a voltage of 480 volts with a frequency of 60 Hz (table 4). Additional load on the service platform can be seen in table 5.

Table 5: Load Addition on the Service Platform

Equipment Addition (359,71 kVA)	Capacity (HP)
Vent Recovery Unit (VRU):	
- 1 motor gas Compressor	300.00
- 1 motor fan lube oil cooler	10.00
- 1 motor water pump jacket	0.75
Replacement of electric motor to pump oil from 125hp to 200 Hp by 1 unit.	75.00

From the data the total power readings on the service platform are known to be 350 kW (with only 2 oil pump motors operating). So, the load to be carried on the service platform is equal to:

$$P_{service} = (350 + 287{,}769)\ kW = 637{,}769\ kW.$$

The principle of generator loading is given that the total load is less than the available power capacity. Based on the power requirements above, 6 parallel generators are needed which will be able to operate continuously and produce a maximum power of 1560 kVA. In generating operation, the total power required on a regular basis is limited to only about 80% of the power output. This arrangement is necessary because it is based on the condition of the efficiency of the gas-fueled engine and the generator only decreased by 80% of its capacity. In parallel working conditions on this platform, normal operation only takes 6 generators operating with 80% loading. So, the power plant on the service platform must be able to serve the new load. However, when the electric motor running, there will be a large inrush current of the motor. So that the loading is limited to only 80% at the operation time.

Calculation result of varied condition load: Motor 300Hp, VRU, Motor 200Hp, Motor 125 HP, Normal Load.

The biggest Power electric motor is the VRU compressor motor with a capacity of 300 Hp or 223.8 kW. Full load current of the motor is P = 336,487A and The VRU the motor starting current is I =0.75x0.70x336,487A= 176.655 A (Assuming LRA is 700%). So, the VRU P_{start} motor is = 1,174.94 kW.

At the Platform Services are 4 units of generators, but can operate only 3 units @ 250kW generators so that the power of 750 kW available. The power load when the VRU starts in parallel is 1338 kW. With the additional load on the Service platform mentioned above, the total load on the service platform is above 100% of the initial capacity. This platform will not be able to accept the addition of a new load. This is a problem that must be resolved. While on the compressor platform, the total load when starting the cooling water pump motor is only 382 kW or only 47.16%. Power on this platform can be obtained from 3 generators so that the total power available is 750 kW.

Multiple generator system parallelization and Load shedding System will be used to solve this problem. At normal operating conditions required 6 stations operating in parallel. When one or more power plants shut down, the existing load shedding control will take care of part of the load that is being operated.

On the basis of the maximum loading of 80%, the load shedding system is divided into four levels of operation, namely:

a. Load shed Level #1 = 4 Gen operating = 1250 kVA, Load service 996.3 kVA, (79.73%)

b. Load shed Level #2 = 3 Gen operating = 937 kVA, Load service 738.68 kVA, (78.79%)

c. Load shed Level #3 = 2 Gen operating = 625 kVA, Load service 493.97 kVA, (79.04%)

d. Load shed Level #4 = 1 Gen operating = 312 kVA, Load serves 223.29 kVA, (71.45%)

Because in this system there is no difference in voltage levels, the voltages at all points are considered the same and the p u method is chosen for the calculation of the short circuit current. For this reason,

S_{Base} = 1000 kVA and
V_{Base} = 480 volts.
Impedance Z_{Base} = 0.2304 Ohm.

The two platforms are combined in parallel in serving the combined load. The main generator (C1) supplies power to the bus bar on the Compressor platform via the main Circuit Breaker. From the bus bar is distributed to the load that passes through the CB of each load C2 - C7 [16].

On the right side is a channel to the Service Platform which will also be simulated as error point-1. This is illustrated by the following series of alternatives (Fig. 4). Since the ratio of the X / R generator ranges from 10-30, and takes a value of 20, then:

RPU = 0.0256pu. Whereas for cables above the R and X values are: R = 0.0168 / 1000 ft, X = 0.079 / 1000 feet. For 3 parallel conductors, obtained, X per unit = 0.004pu and 3 parallel conductor resistance, $R_{p\,u}$ = 0.00083pu. Due to the parallel work of the generator of the two platforms, it is necessary to also calculate the fault current in the installation system.

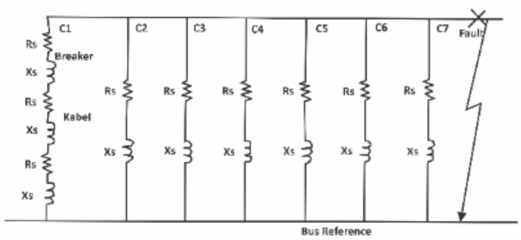

Figure 4. Equivalent circuit for Compressor, Simplification and R-Total platforms

For breaker LVPCB 600AF, 50000 IC: X= 0,0002, then Inductance (X) and Resistance (R) are obtained,

$X_{p.\,u}$ = 0.0009pu and $R_{p.\,u}$ = 0.

From the circuit, the generator, cable and breaker are series connected, so the impedance is obtained:

$X_{p\,u}$ =0.5169pu.

$R_{p\,u}$=0.0264pu.

For 3 generator installed in parallel, an impedance of is obtained

$X_{g\,(3gen)}$ = 0.1723pu and

$R_{g\,(3gen)}$ = 0.0088pu.

The Impedance Calculation can be shown in table 6. From the C1 to C7 circuit can be simplified to

$R_{(comp)}$ =0.0080pu and

$X_{(comp)}$ = 0.1219pu,

Impedance (Z_{comp}) = 0.1222pu.

With I_{Base} = 1202.81 A and

V_{Base} = 480Volt,

The symmetric Fault current to F1 is the symmetric:

I_{SC} = 9,842.96A.

For X/R ratio = 15.275

asymmetrical factor of 1.280.

Thus, the magnitude of the asymmetrical flow towards F1 from the Compressor Platform is

$I_{SC\ Asymmetric} = I_{SC}$ x Asymmetrical Factor

= 9,842.96 x 1,280

= 12,598.99 A.

Obtained by the same method, Short Circuit current on Installation for the Service Platform on the S2-S7 load can be shown in Table 6.

Table 6: Short Circuit Calculation

No.	Information	$X_{(p\,u)}$	$R_{(p\,u)}$
1.	Compressor Platform	0.1219	0.0080
2.	Service Platform	0.0620	0.0049
3.	Cable: X=0.0839Ohm, R = 0.0246 Ohm	0.1725	0.0374
4.	Fault Current To F1 Platform Compressors: $X_{\_s} = X_K + X_S$; $R\_s = R_K + R_S$ = (3 + 2)	0.1895	0.0423
5	Total Equivalent of Service Platform	0.0742	0.0067

I_{SC} = 19,337.78 x 1,250 = 24,172.225 A

The generator connection between the compressor and service platform can be described in Fig. 4.

With the calculation data at table 6 will get
$Z_{p\,u}$ impedance = 0.0745pu and
Current to F1 is I_{SC} = 1.61 kA and
$I_{SC\ asymmetric}$ = 16.1 x 1.24 = 20kA.

The fault current, that Current to F2 Service Platform is symmetric rms current to F2 is I_{SC} = 24.15kA and ratio = 11.27 with asymmetric factor is 1.24 and
So, that $I_{SC\ asymmetric}$ = 24.15 x 1.24 = 29,95kA.

III. ANALYZE OF CALCULATION RESULT

From the calculations performed can be analyzed that:

1. The service platform lacks electricity at 338 kW, whereas on the platform the compressor has excess of 368 kW.
2. The maximum fault current reaches 24.15 kA symmetrically, the fault current in each platform is smaller than 24.15 kA. This means that the current is still below the bus bar capacity (Table 6).
3. Bus bar Strength:
   a. The main bus bar is 50 kA, symmetric,
   b. The branch bar bus is 25 kA. symmetric,
   c. Bus bar generator: 50 kA symmetric.

Table 6. Recapitulation of Power, Capacity and Fault current

INFORMATION	KOMPRESOR	SERVICE	COMBINATION (Parallel)
Total Power (kW)	750/810	750/1000	1810 kW
Total initial load	382kW	163,5kW	545,5 kW
Total load after addition	382kW (47,16%)	1338 (133.8%)	1720kW (95.03%)
$I_{SC\ asymmetric\ rms}$	9.8 kA	19.3 kA	24.15kA
$I_{SC\ asymmetric\ rms}$	12.6 kA	24.17 kA	29.95kA
Bus bar Strength_ main	-	-	50kA_sym
Bus bar Strength_ branch	-	-	25kA_sym
Busbar Strength_ Generator	-	-	50kA_sym

IV. CONCLUSION

From the above analysis it can be concluded as follows

1. Operation optimization of power plant with parallel system between the two platforms can be done because with the two-stage generator, the 1810 kW power plant is sufficient to serve the highest joint load at VRU start, which is a total of 1720 kW. So, The Total power ratio can be increased to be 95.03%.
2. The system still supports parallel operations because the system has a rating above the maximum fault current, namely the symmetrical 50 kA main bus bar strength and 25kA symmetrical branch bus bar strength, while the maximum fault current is 24.15 kA symmetric.
3. To optimize Generator operating (<80%) then load shedding system plans to do selected:

a. Load shed Level #1 = 4 Gen operating = 1250 kVA, Load serves 996.3 kVA, (79.73%)
b. Load shed Level #2 = 3 Gen operating = 937 kVA, Load serves 738.68 kVA, (78.79%).
c. Load shed Level #3 = 2 Gen operating = 625 kVA, Load serves 493.97 kVA, (79.04%)
d. Load shed Level #4 = 1 Gen operating = 312 kVA, Load serves 223.29 kVA, (71.45%).

V. REFERENCES

[1] Vinicius Zimmermann Silva, Angelo José Junqueira Rezeka Christel Enock Ghislain Ogoulola, Alternatives to control the frequency increase in an electric system with synchronous and induction generators in parallel operation mode, Electric Power Systems Research Elsevier, Volume 180, March 2020, https://doi.org/10.1016/j.epsr.2019.106136.

[2] Bonggas. L.Tobing, "Fundamental of High Voltage Measurement", Erlangga Publisher (In Indonesian), Jakarta, 2017.

[3] Budi Lukman, Power Engineering, UI Press Publisher Inc. (in Indonesian), Jakarta, 2010.

[4] María Gasque, Pablo G-Altozano, Rosa P Gutiérrez-Colomer, Eugenio García-Marí, Optimisation of the distribution of power from a photovoltaic generator between two pumps working in parallel, Solar Energy, Vol. 198, 1 March 2020, Pages 324-334. https://doi.org/10.1016/j.solener.2020.01.013

[5] Ranjana Arora, S.C.Kaushik, Rajesh Arora, Thermodynamic modelling and multi-objective optimization of two stage thermoelectric generator in electrically series and parallel configuration, Applied Thermal Eng. Vol.103, 25 June 2016, P.1312-1323. https://doi.org/10.1016/j.applthermaleng.2016.05.009

[6] P.Neuman, Island Operations of Parallel Synchronous Generators - Simulators Case Study for Large Power Plants, IFAC-Papers Online, Vol. 49, Issue 27, 2016, P-164-169, https://doi.org/10.1016/j.ifacol.2016.10.737

[7] Integrated Publishing Inc., 6230 STONE RD, UNIT Q, PORT RICHEY, FL 34668, USA. http://www.tpub.com

[8] Subianto, "Current Relay of Feedback Power", National Journal in University of Palembang, (in Indonesia) Indonesia, ISSN, 2089-2942-2015.

[9] Laksono, H. D., Revan M, National Journal, Analysis of Response Performance of Generator Excitation System Voltage on Parameter Changes, (in Indonesia) Electrical Dept. Univ. Andalas, Indonesia .ISSN, 2302-2949-2014.

[10] M. Zielichowski, Third harmonic ground-fault protection system of unit-connected generator with two parallel branches per phase, Electric Power Systems Research, Vol.78, Issue 1, January 2008, Pages 49-57. https://doi.org/10.1016/j.epsr.2006.12.010

[11] Waluyo, "Design of Electrical Installation Application of Cable Selection System and Disconnecting Switch", National Journal (in Indonesia) Elect. Depart, ITN, Indonesia. ISSN : 2337-4396, 2013

[12] University of Sumatera Utara report, "Short Circuit Calculation by per Unit Method", (online), http://Repository.usu.ac.id. North Sumatera, 2017.

[13] Farid H, "Voltage Drop and Short Circuit Current Analysis at Medium Voltage Network (JTM) PT RUM", National Journal, (in Indonesia) Electrical Depart, Univ. Diponegoro, ISSN 2302-9927, 2017.

[14] Standard NEMA (National Electrical Manufacture Association), converting to symmetrical rms Ampere. P.15, USA, 2017.

[15] Standard, NEC and NFPA (National Fire Protection Association). Quincy, Massachusetts, USA, 2017.

[16] R.H. Sianipar, "Electrical Circuit", Science Engineering (in Indonesia), Bandung, 2015.

[17] User Manual Book Woodward, Generator Load Sensor, Prod Specification 82314 (Revision, 12/2001)

[18] ABB Report Power T&D Company Inc, Reverse Power Relay, Instruction Leaflet 41252A, Dec 1996.

[19] One Line Diagram of Electrical Drawing LIMA F/S. PT.PHEONWJ (Internal), 2005.

[20] Journal NPTL, (National Programme on Technologies Enhanced Learning), http://nptel.ac.in Bombay, India, 2017.