Sulimani-unversity 6x2200KVA Generators Parallel operation

Islanding mode

Electrical Engineer Khaldoun Sami

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Abstract

This report was done by the group of ITSC –Sulaimania to operate

And tune the 6x2200KVA generating station in case of mains failure

As island (standby, prime power) modes .

It gives guidance for evaluating the best configurable parameters that can be fed in next to common synchronizing system . The report discusses necessary typical data for parallel operation , generators relaying protection depending on IEEE standards [2-3] and provides highlights data base for the generators coordination future scada work.

Table of Contents

1. Introduction

Control scheme aims to obtain satisfactory power system with stabilized Frequency and bus voltage, maintains load and reactive power flow.
We use feed forward control that can be established in wood ward microprocessor controllers (EGCP-1) taking benefit of network sharing among them. The control scheme is type of load frequency control scheme based on primary frequency control and secondary net bus power demand controlling which gives best stable system instead of using single control loops.
The System consists of 6x2200KVA FG.Wilson generators with wood ward Control panels (6200) Appendix A, operate in iso -chronous isolated mode with:
- Isolated no mains parallel (standby or prime power)
-active and reactive power sharing (power factor controlling).
-load management and auto sequencing for start /stop.
The sharing communication network is based on RS-485, with mod bus protocol which configured as one master station at any given time According to priority levels in (6200) controllers, to maintain the balance between the electric power produced by the generators and the balance consumed by the loads, including the network losses, at all time instants.

We face two main proplems:
1-no common synchronizing panel fig (1) for all generators at level 11kv bus bar that takes measurement from each generator and compare with one measrement point at 11kv bus (voltage transformer siemens 4RM12).

2- No scada system incorpurated in for selection , operation of generator sets and download parameters configuration for wood ward controller.

We overcome these two proplems by:

1-configuration of the controllers manually and by using labtop with modbus link RS-422, and letting the master controller to take the full control scheme

2-make the synchronizing in each generator controller at low tension

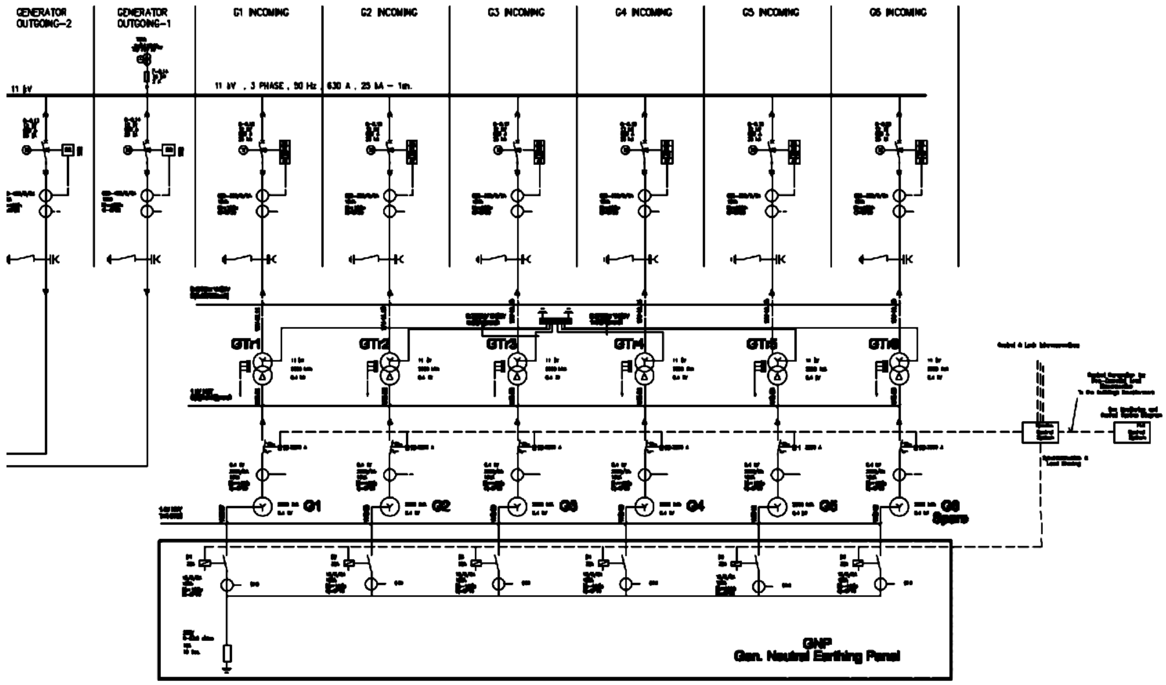

Figure 1 Sulaimani University Generation Station, Tebe

Drawing no. SUC.DE.ST.E.MV.R5

2 Theoretical investigation

2.1 principle of synchronous generator I.Boldea,2006 [9]

the operation of generator depends on fraday law ,inducing Emf
it consists of mainly two parts:
-magnetic field set up
-energy flow from prime mover

The magneting sets arevolving field in the gap between stater and rotor at synchronous speed,the induced emf in rotor and due to outside circuit load will produce current that produce an interacting field (armature reaction) the resultant field determine operation charaterstics.

The difference between alignments of rotor axis and magnetic field determined by the power angle (δ) ,with the damping winding shorted in rotor for producing counter torque to keep the two speeds (magnetic gap and rotor)close In case of distribunces affecting them.

In big synchronous generators the winding resistance (Ra) is small compared with synchronous inductace ohm (Xs),(Xd+system reactance) which contains armature reaction inductance , so the out put power (Sog) which is composed of real power (Pog) and reactive power (Qog) related , K.Vasudevan,[7] .

Sog=Pog+jQog (1)

Where j denote complex factor
If (Vt) the terminal voltage per phase,(Ia) the phase current
Then the excitation emf(Ei) is:

Ei=Vt+Ia(Ra+jXs) (2)

where the thick letter present vector
And (Xs) can be determined from open ciruit (OCC) and short circiut Test (SCC) such that:

Xs= If (OCC)/If(SCC) in per unit (3)

,where If denotes the field current in the tests.

Equaion (1) can be expressed as :

Sog=Vt*Ia

=$Vt(\frac{Ei-Vt}{XS})$* where *denotes complex conjucate

And if we take terminal voltage as refernce vector with zero phase angle,Ei with (δ) power angle ,then

$Pog=VtEi/Xs\ sin(\delta)-Vt^2Ra/Xs^2$ (4)

$Qog=VtEi/Xs\ cos(\delta)-Vt^2/Xs$ (5)

Max out put power occurs at power angle equal to synchronous impedance angle

Pog(max)=Ei.Vt/Xs (6)

The term in right of equation(4) represent the ohmic losses

For big generators Ra is neglected in comparision to synchronous reactance Xs so

Pog=VtEi/Xs sin(δ) (7)

And the reactive power remains as in (5),if we take Vt as reference phasor

We can plot the active power (p) and reactive power scales to form the capability curve for the generator

Ei constant excitation correspoinding to constant field current in rotor

Max value will limit heating in rotor besides heating from eady current in under excited region in fig.(2) resulting from negative(Q)flows into generator

max power output is limited by prime mover cabability ,besides the ohmic lossess in statator winding caused by max (Ia).

The power circle equation is coming from

$|Sog|^2 = |Pog|^2+|Qog|^2$

$|Ei*Vt/Xs\ |^2=|P\ |^2+|Q+Vt^2/Xs\ |^2$

Where P,Q corresponds to the active and reactive power of the generator

Neglecting resistance losses.J.J.Grainer and, W.D.Stevenson [15].

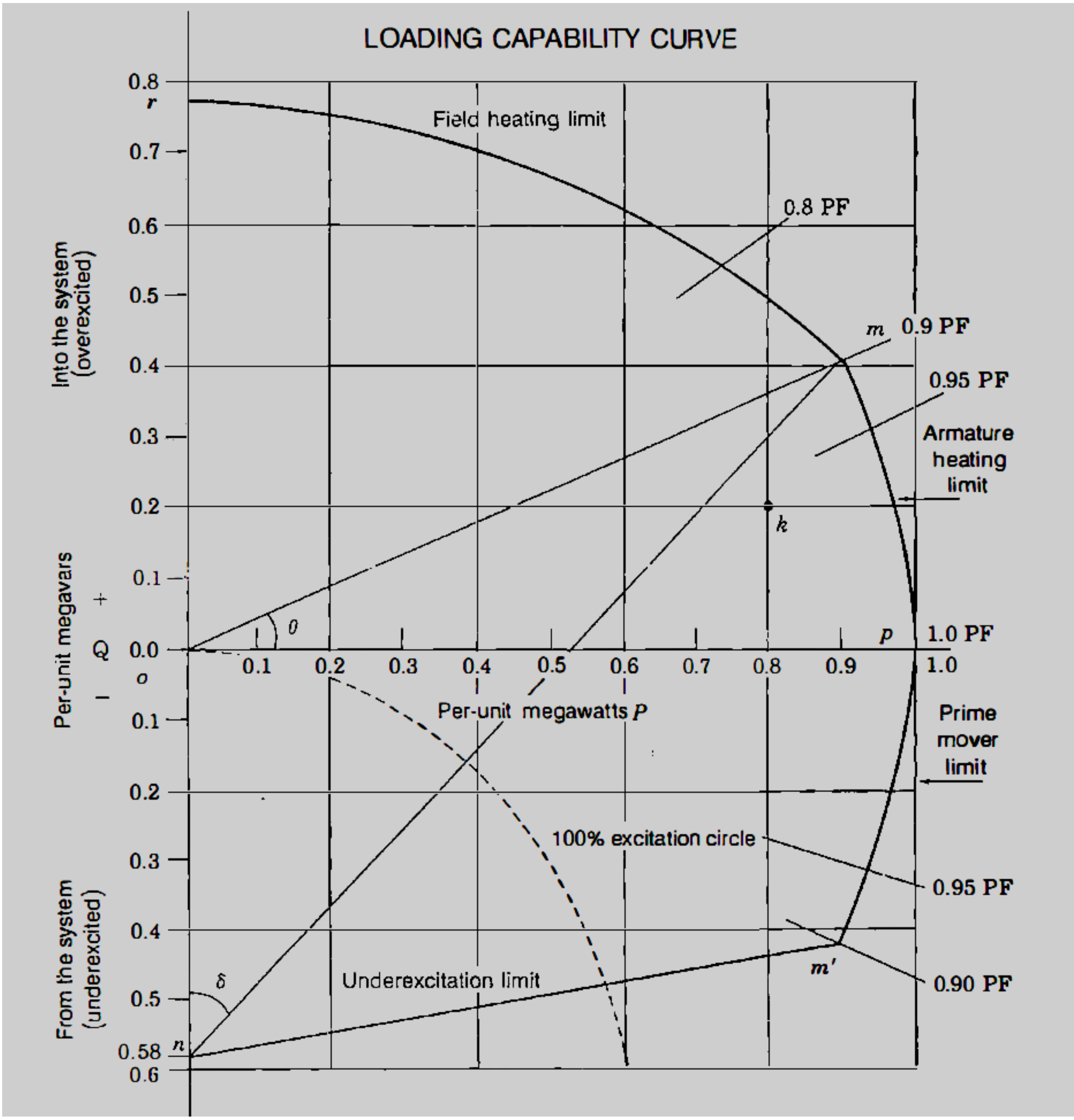

Figure 2 Typical generator capability curve , [15]

2.2 Power sensor and dynamic theory of operation

The microprocessor unit (EGCP-1)uses digital discrete technique involves periodic sampling of voltage and current over integral numer of wave forms and the unit computes the product of the measured values and sums –avarages the products to give the computation power.the system is combined with digital load sensor that gets the timing information from agenerator A phase voltage signal with voltage proportional to the each phase voltage and load current and are routed to analog to digial convertors.

The EGCP-1has four mode of operation:

1-droop

2-isochronous

3-base load

4-process contol

in iso-chronous mode,the generating set operates at same frequency regardless of load, the generators attain to have load sharing cabability to prevet them from motoring or taking the full load by part of the generator sets

The load sensors of EGCP-1 are connected by intercontrol RS-485 Network, any imbalance in load between units will cause achange to the control unit in each governor,while keeping each machine runs at its rated speed ,these changes force each generator to share the required power to meet the total demand.

D.Beeman ,1955[1] explains the voltage dips recovery time under induction loads and calculating the voltage drop during starting, FG Wilson generator has the capability to overcome motor staring at 0.6 pf and capacity up to 6500 kva with dip voltage 30% . His suggestion

For neutral switching sequences (GNP)Siemens panel figure (1), One or two neutral contactors switching for more ground current fault sensitivity is taken into consideration in our system

k.p.padiyar ,2008 [4] describes the generators models at steady and transient operation, he introduces the reactance values during different time :

1-Xd for steady state operation but during generator connected to bus its excitation increases to supply Xs instead of Xd , since Xs

Xs=Xd+ external circuit impedance.

2-Xd¯ for transient short circuit neglecting the effect of damping winding in rotor

3-Xd″ at instance of short circuit lasts for few cycles ,

And covers them in rotor swing dynamic equation

$$M*\frac{d^2\theta m}{dt^2} = Pm-Pe \qquad (9)$$

Where $M = J * Wm$ is the angular momentum. J is the moment of inertia of rotor, Wm is the rotational average speed in rad/sec.

It is convenient to express Θm as

$$\Theta m = \delta m + Wm * t \qquad (10)$$

where δm represents average power angle, $so\ equation\ (9)$ is

$$M * \frac{d^2 \delta m}{dt^2} = Pm - Pe \qquad (11)$$

1- **Steady state power angle to be stable is $\frac{dPe}{d\delta} \rangle 0$**
2- **For transient stability single generator the equal area criterion is used page (29-32), K.P.Padiyar , 2008 [4].**

   G.Andersson[6] introduces the swing equation in state space form Using the following formula:

   $$2 \sum \frac{Hi * SBi}{wo} \Delta wi = \sum \frac{wo}{wi} (Pmi - Pei) \qquad (12)$$

   Where:

   Summation is for all numbers of generators connected to bus

   I represent machine number

   Hi represents constant of the machine inertia (sec),F.G.Wilson generator has (0.7-0.8) sec inertia constant, which represents the amount of kinetic energy that can be stored with respect to rated MVA .

   Pmi represents the mechanical prime mover power

   Pei represents the electric input power of generator

   Wo is the normal angular velocity before disturbance rad/sec

   Wi is the absolute value of angular velocity rad/sec

   $\Delta wi = wi - wo$

Defining the following quantities

W= $\frac{\sum_1^n Hi*wi}{\sum_1^n Hi}$ **center of inertia frequency**

SB= $\sum_1^n SBi$ **total rating**

H= $\frac{\sum_1^n Hi*SBi}{\sum_1^n SBi}$ **total inertia constant**

Pm= $\sum_1^n Pmi$ **total mechanical power**

Pe= $\sum_1^n Pei$ **total electrical power**

Taking the disturbances in electrical load and mechanical power, converting the angular speed to the frequency parameter equation (12) ,Can be represented as

$$\Delta f' = \frac{fo}{2H*SB}(\Delta Pm - \Delta P\ load) \qquad (13)$$

Where ∆f′ is the frequency time derivative, equation (13) plays the rule for relation between frequency controls in secondary loop to balance load demand fluctuations, in Figure (6) the same method is used for primary frequency/power secondary control, and Same procedure is introduced for voltage and reactive power control algorithm [6].

3 Synchronizing

Synchronization, as normally applied to the generation of electricity, is the Matching of the output voltage waveform of one alternating current electrical generator with the voltage waveform of another alternating current electrical system . For the two systems to be synchronized and connected in parallel, three conditions must be considered:
No. of phases and rotation are fixed are done after installation one time, Besides the following variable parameters

- the voltage amplitudes of the two systems
- the frequencies of the two systems
- the phase angle of the voltage of the two systems

The synchronizer matches the (Voltage, frequency, and phase) before the paralleling breakers are closed.
This section describes how generator and bus matching occurs and how all Conditions are verified by the synchronizer function, M.J. Thompson, 2010, [11], describes the protective relay grade that can improve synchronizing system and requests the following setting:
-phase angle ±10°
-voltage ±0.5%
- slip frequency 0.1 HZ
After measuring the slip then calculates the phase advance for compensation of circuit breaker closing time, he suggests the following formula
Advance angle=slipx360 (TCLS)/fn . (10)
Where TCLS repesent the closing time of circuit breaker (cycles)in our system its ABB-E3N32 –EMAX with :
TCLS= max (80 ms).
And the advance angle will be (1.4°) from equation (10).
Equation (10) to be added to synchronizing relay delay time correction to get more accurate value ,basler ,2012, [8] .
In our system synchronizing is done automatically by EGCP-1 for each generator after receiving command from master through RS-485 net, synchronizing can be done with live busbar after success the dead bus connection by another.

Balser explains the continous automatic synchronizing with additional request as:
the rated generating capacity of the iso –landing system exceeds the demand load.
From this point the synchronizer will set the new incom ing Frequency as greater than the bus to absorb the impact of the load

During synchronizing. The phase matching synchronizing mode corrects the frequency and phase of the generator to lock it to the bus frequency and phase. The microprocessor uses signal processing techniques to derive the difference in phase of the generator A and bus A phase voltage signals (RMS). When there is a difference, the synchronizer sends a correction signal to the speed control. The correction signal from the speed bias output increases or decreases engine speed depending on whether the slip is faster or slower than the bus. A PI (proportional, Integral) controller provides the correction signal. Gain and Stability adjustments to the PI controller are provided to allow stable operation of the automatic synchronizer function over a wide range of system dynamics.

The following steps will be done by synchronizer In sequences

a-compare voltage
b-compare frequency
c-change voltage to match bus
d-change frequency to match bus
e-compare phase angle
at this point the synchronizer gives corrective signals to the oncoming generator to complete the match. The following cases prevent synchronizier closing command:
-the correction of AVR is out of limits for specified time
-the correction speed controller is out of limits for specified time
-voltage and frequency of generators is out of limits for specified time

The closing command is given in slowing rotating approaching

zero phase angle from the advanced angle calculated earlier.

The phase matching is the final before closing command issue,it corrects The frequency and phase of generator to look it with the bus.EGCP-1 Uses the measurement on phase A for comparision,any differences will make synchronizer through (PI) controller algorithim to send the correction signal tpo the speed controller (PRO-ACT)WoodWard (9905-463) , this (PI) controller can achieve speed regulation as In iso-chronous mode (±.3%) of rated speed .after correction the synchronizer to enter the check mode and decides the closing timing shoots,reclosing activities.
For voltage regulation algorithim is done by the leroy –somer AVR R449 with the following setting as typical:
Drop set =3.0% which is lelated to (CT)current flow connected to AVR Input correction signal from synchronizer as ±1VDC, with (0) biasing that can regulate Outbut votage ±10% of rated voltage. And this can cover transient load applied (100%) to be regulated to 2% of rated voltage . M.J.Thompson,2010,[11].

In M.Htay [13],the AVR properities for maintaining generator voltage in wide range of load current and good response time recovery for transients is proposed,AVR R449 leroy somer ,fig.(3)uses both three phase voltage and current measurement to get stable closed loop colntroller.excitation system is provided through independent coils of stator load which makes the excitation supply constant for wide current range. The microprocessor then computes the RMS values of the voltages. The processor issues appropriate adjustment of the voltage bias signal if used, to the voltage regulator to bring the generator voltage within the specified window above the bus voltage. To guarantee that reactive power will be generated, window range is from equal to bus voltage to the specified percentage above bus voltage.
The operation of the synchronizer is determined by the three different operating modes available in the EGCP-1 : Run, Check, and Permissive. Run mode allows normal synchronizer operation and breaker closure signals. The speed bias signal is maintained throughout the breaker closure signal. When the specified closure signal time has elapsed and

the CB(circuit breaker) Aux contact closure signal is received at the EGCP-1, the synchronizer is disabled. The synchronizer is reset automatically once the generator is taken off load and its generator breaker is opened.

Check mode allows normal synchronizing and voltage matching, but does not issue a breaker closure signal.

Permissive mode enables the synch-check function for proper synchronization, but synchronizer operation does not affect the engine's speed or generator voltage. If phase, frequency, and voltage are within proper limits for the specified dwell time, the synchronizer issues the breaker closure command.

A larger Max Phase Window and Shorter Dwell time would typically be used on emergency standby sets, where rapid synchronization is needed. The larger window and shorter dwell time make the synchronizer less sensitive to transitions in generator frequency and phase angle error when compared to the bus the generator is synchronizing to. When all conditions of voltage and phase are met, then the breaker closure command is given. A smaller Max Phase Window and Longer Dwell Time would be used on generating systems where smooth and precise synchronization is required, and the time to synchronize is not as critical as would be seen in a standby application. Our setting is for fast synchronizing with low dwell time (5 sec).

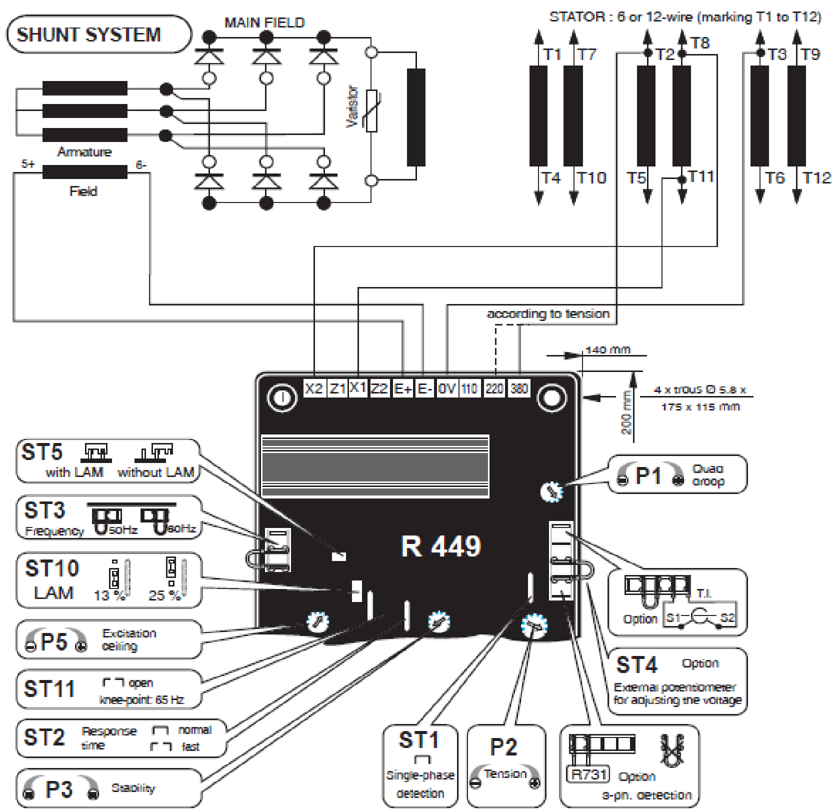

Figure 3 AVR-R449 and excitation system

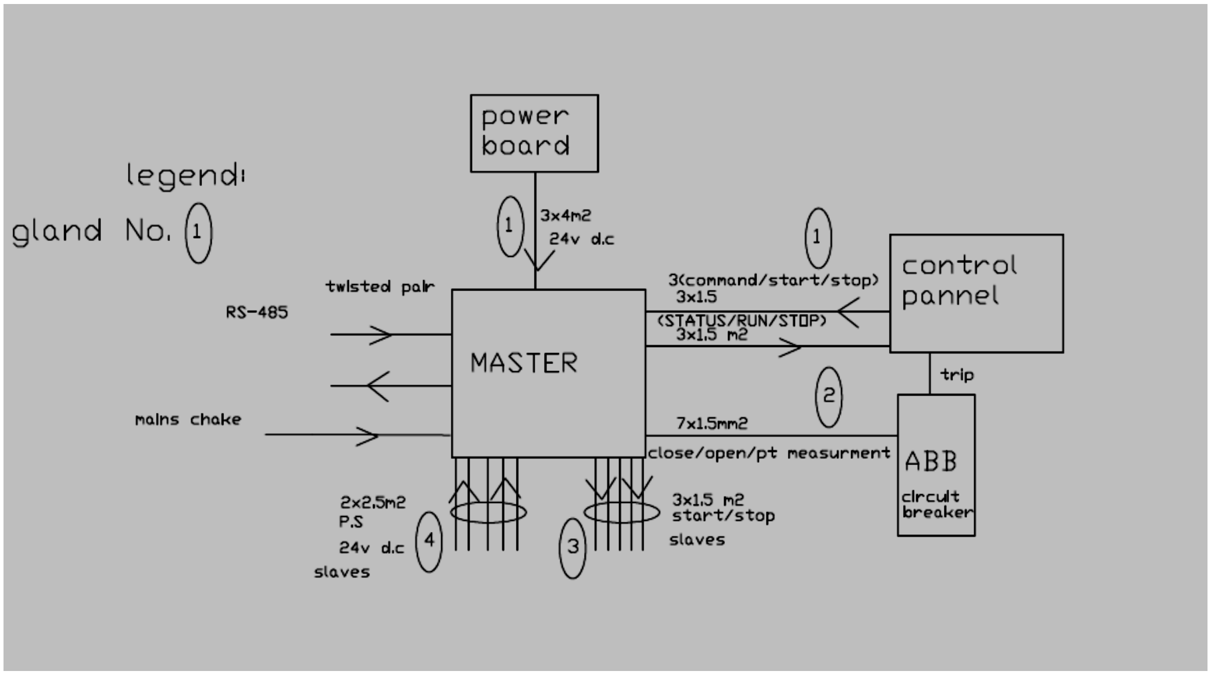

Figure 4 master controller connection

4 Auto sequences

The EGCP-1 can perform Start/Stop sequencing in isolated parallel. The decision to start or stop an engine generator set are made by the master unit according to the configuration settings in the Sequencing and Communication menu.

.

The stop sequence begins with at least two generators running on-line.

1. after the master unit closes to the bus, the Auto Sequencing Delay time starts (125sec). This timer is used to delay the Sequencing function for a period of time, when loads may be returning to bus or to allow all of the engines a minimum run time.

2. following the Auto Sequencing Delay, the master unit will monitor its System Load percentage using RS-485 net.

3. If this load percentage is less than the Min Gen Load setting (450KVA) for the Reduced Load Delay timer (5sec), the unit with the highest priority number will be commanded to stop, if the Master calculation for removing this unit will cause the load to increase to within suitable dead band that cannot start unit again .

4. The slave unit unloads to it's unload trip point (5%), Opens its generator breaker and goes into the stop sequence.

5. The Max Stop Time timer is started (60sec). The master unit will wait for the Max Stop time (60sec), before sequencing another unit off the bus. This delay is used to allow a unit enough time to unload and shutdown, before the master commands the next unit to start or stop.

- **Sequencing for Units that had been stopped by the master, may be commanded to start again if the load were to increase on the bus. This sequence begins with the at least one slave having been stopped previously by the master.**

1. If the system load exceeds the Max Gen Load set point (1200KVA) for the Next Genes' Delay time (20sec) the Next On engine will be commanded to start

2. The Max Start Time timer is started (30sec).

2.1. The master will not command another unit to start until this timer has finished
2.2. If the unit fails to crank and logs a Fail to crank alarm, it will be skipped and the next priority unit will be commanded to start, following the Max Start Time (30 sec).
3. The engine starts and synchronizes to the bus.
4. The EGCP-1 will ramp its load set point from the unload trip level to the System Load percentage of the other generators on-line and begin sharing the load.
A special situation occurs if the master is loaded beyond its rated capacity. The EGCP-1 uses the Rated Load Delay time to start an engine sooner if the master becomes overloaded. The Rated Load Delay time (5 sec) is intended to be set to a value less than the Next Gen set Delay time.
• If a unit is started because of a Rated Load start, the Idle Rated timer is skipped in the start sequence
• The Load ramp is also skipped. The on-coming unit will try to match the system load percentage after its breaker is closed to add capacity as quickly as possible.
fig.(4) the Connection schematic for master with slaves is shown ,table 2 list setting for load sharing and control menu.

5 Multiple (prime power/standby)operation mode

The configuration parammeters in EGCP-1 units as follows:
1-generator unit address (unique address for each generator)
2-number of units (multiple)
3-operation mode (no parallel)
4-check mains breaker (enabled) only master can take action
For prime power this is disable.
5-at least one of the four loss of mains (bus frequency high/low,voltage high/low) set for that action.
6-auto sequencing (enabled)
Besides the parameters for delay action,max generator load,min generator load,starting time and stopping time.
The master will sent signal (start/run) commands according to parameters configured in master the run command will stay about two minutes to let all generators to synchronized during intial start up after receiving loss of mains signal by the master.this mode is:
-master system run and commands slaves as system needed
-slaves auto run
In auto run the slave will operate indepentily from master and after Removing the run command it will enter master follow mode, where the slave will start/stop according to master commands depends on the max generator load/min generator load and enter PF sharing.
(if the master fails ,the second higher priority will be the master till

The original one is repaired, see fig.(5)

Table 1 lists all possible operation modes, one can select as system

Requirement, we use prime power with sequencing in sulaimani-

Campus.

Table 1 EGCP-1 control modes for mains no parallel

item	control	Auto	Auto-run	mode
1-	Master	Standby: starts by mains failed signal Will issue start commands to slaves in stand by	Starting with out need for mains failure	Stand by no sequences
	Slave	Stand by: started either by 1- Mains failure 2- auto run	Starting without need for mains failure	
2-	Master	Stand by :starts master on mains failure and issues start command for slaves in master follow as needed	Run system issues commands to master follow slaves as needed	Stand by with sequences
	Slave	Master follow will take command from master	Runs independent of master	
3-	Master	Auto no action	Auto run	Prime power no sequences
	Slave	Auto no action	Auto run	
4-	Master	Stand by (by setting mains low voltage as loss of mains):will start	Auto run: starts and will start slaves as needed as long as auto is closed	Prime power with sequences
	Slave	Master follow :started and stopped by master	Auto run :start independent of master	

5.1 alarm types

Besides warning and audible alarms there are two other main types

1-Soft Shutdown

When an alarm set point is set for Soft Shutdown, the alarm condition will cause the generator to ramp off load, unless it is the only unit carrying the load in which case it will immediately open its gen breaker. If the unit has carried load above its cool down limit, the unit will also cool down and then shut off. The audible, and visual alarm relays will energize at the time of the alarm condition, and the red LED on the face of the EGCP-1 will stay on continuously. Acknowledging the alarm condition will cause the alarms to reset, and make the unit operational once again.

2-Hard Shutdown

When an alarm set point is set for Hard Shutdown, the alarm condition will cause the generator to immediately open its breaker, and immediately shut off. The audible, and visual alarm relays will energize at the time of the alarm condition, and the red LED on the face of the EGCP-1 will stay on continuously. A unit, which has experienced a hard shutdown condition, will remove itself from any automatic sequencing displays. Acknowledging the alarm condition will cause the alarms to reset, and make the unit operational once again

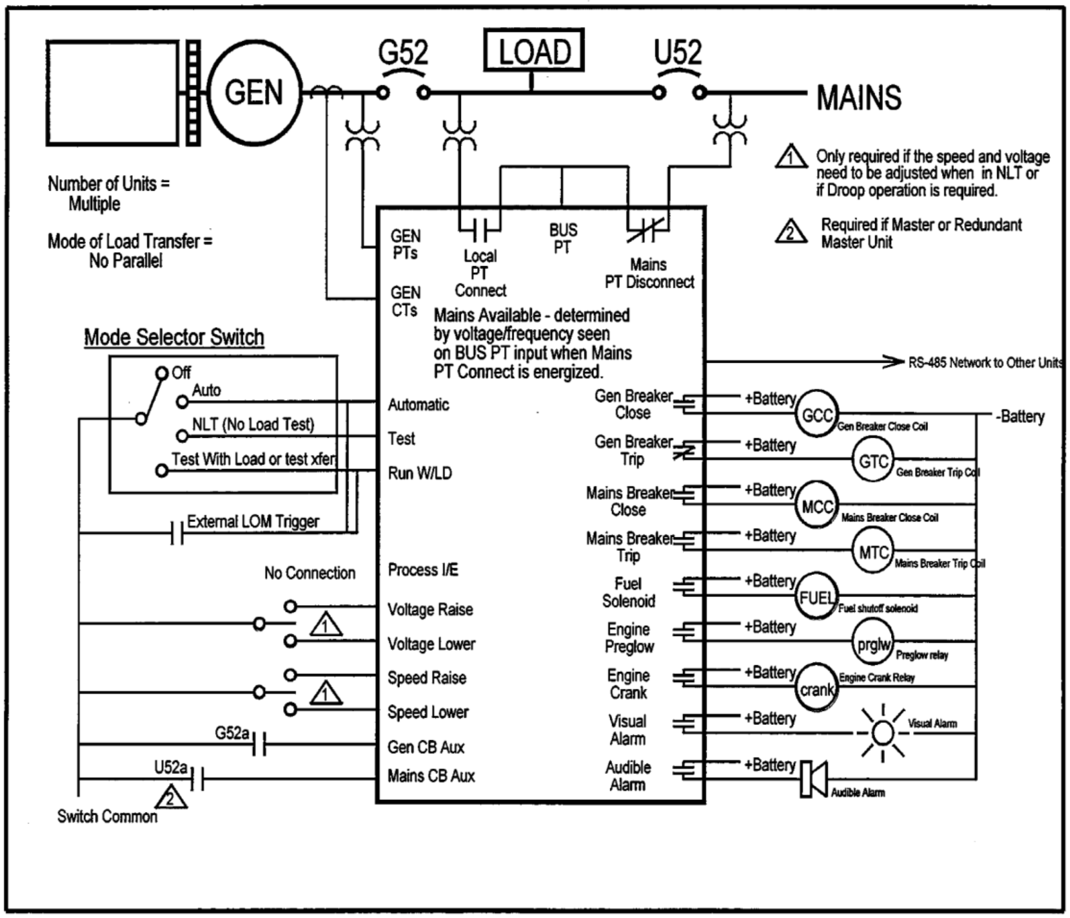

Figure 5 multiple units no parallel schematic

6 load sharing

using (EGCP-1)Wood Ward that can communicate with the other controllers using RS-485 that introduces mainly:
-dead bus synchronizing this is done either by master or any slave that Complete checking for supplying load at first
-calucted the actual power and actual reactive power in the 11 KV bus supplied by the generators in island mode
-automatic sequencing of slaves (start/stop)
-load sharing(active and reactive)
-detection of generators circuit breakers status to ignore dead bus Operation.
-automatic mains failure detection by the master
-checking the priority for each generator and its status these data Are collected in to master through the network.

Actual load is the summation of the power of each on generator(PGN.tot),and the total rated power is the summation of indvitual rated(PG.rat)
So the the total utilization factor is calculated throgh RS-485 in master as:
Total utilization factor= PGN.tot/ PG.rat
And compared with master utalization factor(P .act/P.rat)
The result will contribute with frequency deviation(f-fn) to get the required error that acting on the controller for final action on prime mover.
i.e:
error=k(total utilization factor-unit utilization factor)+(f-fn)/fn.
Where (f) is the measured frequencyand (fn) is the rated one.
(K)value will determine the control action direction towards Primary frequency control or secondary active power control Figure (6).

The procedure applies on voltage bus regulation in associacion

With reactive power control anf sharing.

C.f.ten and p.a.crossely,2010,[10],Y.ZHANG,2009, [14].

Isochronous Load Sharing is the most common means of paralleling multiple generators together to a common load on an isolated bus. The

. Isochronous load sharing operates all generator sets in a system in the isochronous mode. Load sharing is accomplished by using the load sensor of the EGCP-1 to bias the speed reference of the isochronous governor. The EGCP-1 load sensors are connected by inter-control RS-485 network, any imbalance in load between units will cause a change to the regulating circuit in each governor. While each unit continues to run at isochronous speed, these changes force each machine to supply a proportional share of power to meet the total load demand on the system.

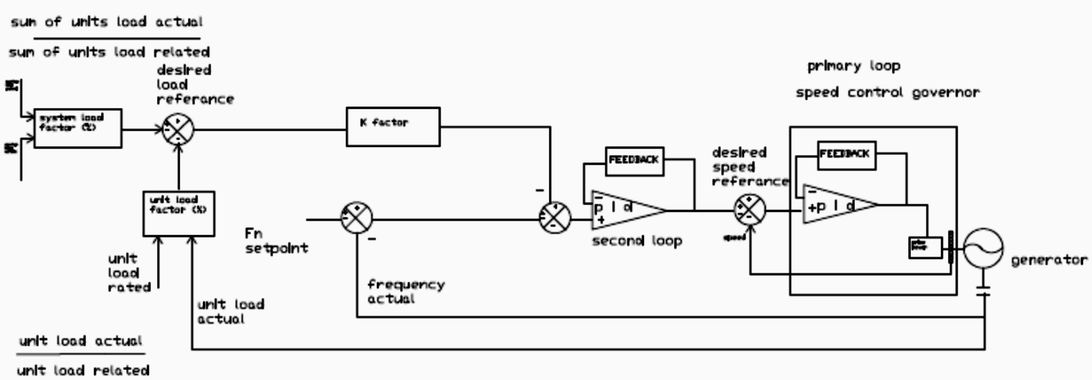

Figure 6 primary/secondary load frequency contol

6.1 Power factor sharing

When power factor control is selected,and the generators are operated in load sharing isochronous mode then power factor sharing is automatically selected.
In power factor sharing voltage is adjusted so that the generators to carry the same proportion of reactive power load by balancing the power factor of all operating uints, while maintaining the bus voltage around reference value.
The followig settings are introduced
-VAR/PF gain=1.0,
-volt ramp time=100 sec
- VAR/PFsharing gain=0.2
- VAR/PFsharing integral time=2 sec
PF dead band= 0.005 ,P.Kundur, [5]

When either VAR or Power Factor Control is selected, and the EGCP-1 control is operating in isochronous load sharing mode, power factor sharing is automatically selected. Power factor sharing adjusts the voltage regulators so that all generators carry the same proportion of reactive load by balancing the power factor on all units. A voltage reference set point is provided to define the system operating voltage. Multiple EGCP-1 controls operating in Power Factor sharing mode will trim their respective voltages to share the reactive load on the isolated bus, and operate around the voltage reference setting.

7 Generator Protective Features (alternator)

the following are the trip setting for the generator/alternator IEEE std [1], [3].

1-over voltage (59)

Setting value : 130% at 2.5 sec

2-under voltage (27)

Setting value:80%Vn at 2 sec

3-over frequency (81O)

Setting value :50.5HZ at 5sec

4-under frequency (81U)

Setting value: 49.5HZ at 10sec

5-reverse power (inverse time delay) (32)

Reverse power protection prevents generator from motoring on loss of prime mover thus prevent real power from entering the generator and while the field current excitation is flow the generator continue to be in synchronisim but acts as synchronous motor,till the field cicuit opening in that case the generator will act as induction motor.

Setting value :less than 15% of rated power at 15 sec

6-loss of excitation (40G)

the excitation system of the generator is of independent aux.winding type AREP with AVR (R449) , voltage regulation ±0.5%

the AREP has two winding :

-First with voltage proportional to alternator voltage

-Second with voltage proportional to stator current

Thus the system works with shunt characteristics and boosting

The reactive out put power (Qog) of synchronous generator can be expressed in (5) as:

$$Qog = \frac{V_t E_i}{X_s}\cos\delta - \frac{V_t^2}{X_s} \qquad (5)$$

$=Vt/Xs(Ei \cos \delta - Vt)$

Where the term $Vt/Xs(Ei \cos \delta)$ represents mainly the internal generated reactive power which is related to exitation field,the other term Vt^2/Xs represent the flow of reactive power into the generator Which will remain in case of loss of exitation.If a Synchronous machine losses the Excitation, the following condition will occur:

- Reactive power flows from the other generators into the generator.

- the synchronous generator will operate as an induction generator, supplying essentially the same KW to the system as before the loss of Excitation.

-Since Synchronous generator is not designed for asynchronous operation, the machine output will oscillate slightly as the rotor oscillates in an attempt to lock into synchronism.

-Loss of Synchronism does not require immediate tripping unless there is an accompanying decrease in the terminal voltage that threatens system stability; it generally takes about 4 sec. to lose synchronism.
So the machine wills loss stability after losing excitation.
From practice it s around 0.95 leading power factor where the rotor limitation occurs, See figure (2)
In our system the setting is done by the percentage of reactive power flow into the generator. This algorithm was introduced by Turk J Elec Engin [16] that based on measurement of three phase reactive power Monitors its direction and magnitude regardless of reverse power, letting AVR to correct during swing dynamic transient.
Setting value: (15%-20%) reverse reactive power for 2 sec
7-over speed 120%
8-over current (inverse time delay) (51)
Setting values:200% FLC at 6 sec

Short circuit capability: 300%FLC AT 10 sec.
Where (FLC) refers to the full load current which in our case equal (3200 AMP)
9-loss of mains detection either under voltage or under frequency alarms, We use this alarm as (AMF)automatic mains failure action for automatic start up of generators in standby mode.
10-speed/frequency mismatch numerical setting about 20%
11-Ground fault (50G) triggers externally by neutral ground resistor which is connected on common neutal bus through switching board and since the generators are symmetric with generator step up transformers of Δ/Y connection, current circulating harmonics is reduced Common Resistance fault current about 10 AMP and the ,Setting value (1.0) amp at 3 sec for each generator [2]. The setting will depend on first fault current of single phase to neutral point

8 networks

RS-485 communication link allows load sharing,status,and command messages to be exchanged between the generators,the network uses twisted shiled pair to link the units the end generators (1,6) to set their dip switches for termination the loop.

The network does the folowing main actions:

1- **dead bus synchronizing**
2- **determine the master at any instant**
3- **transfer of contol to another master in case of present master malefunction**
4- **load sharing**
5- **power factor sharing**
6- **auto starting of slaves commands**
7- **auto stopping of slaves commands**
8- **check mains breaker status (Siemens)**
9- **check mains avaliablity**

10-check generators breakers status(ABB)

11-generators status,priority and network address

12-show on master sequence secreen start/stop next generator number

13-show status of slaves on master sceen

14 . the master can see slave flags for completing starting and stoping commands before issue the commands to the other ones.

the other network link is RS-422 to facilitate the use of computer for monitoring and download the configuration and can be connected to scada futue system.
RS-422 usese either modbus or Service link protocol in multi-drop linewhich allows connection to external devices,lap top to use RS-232 to RS-422 convertor to work fig(7)
RS-422 net is used for remote up/down loading, control and monitoring via scada system.

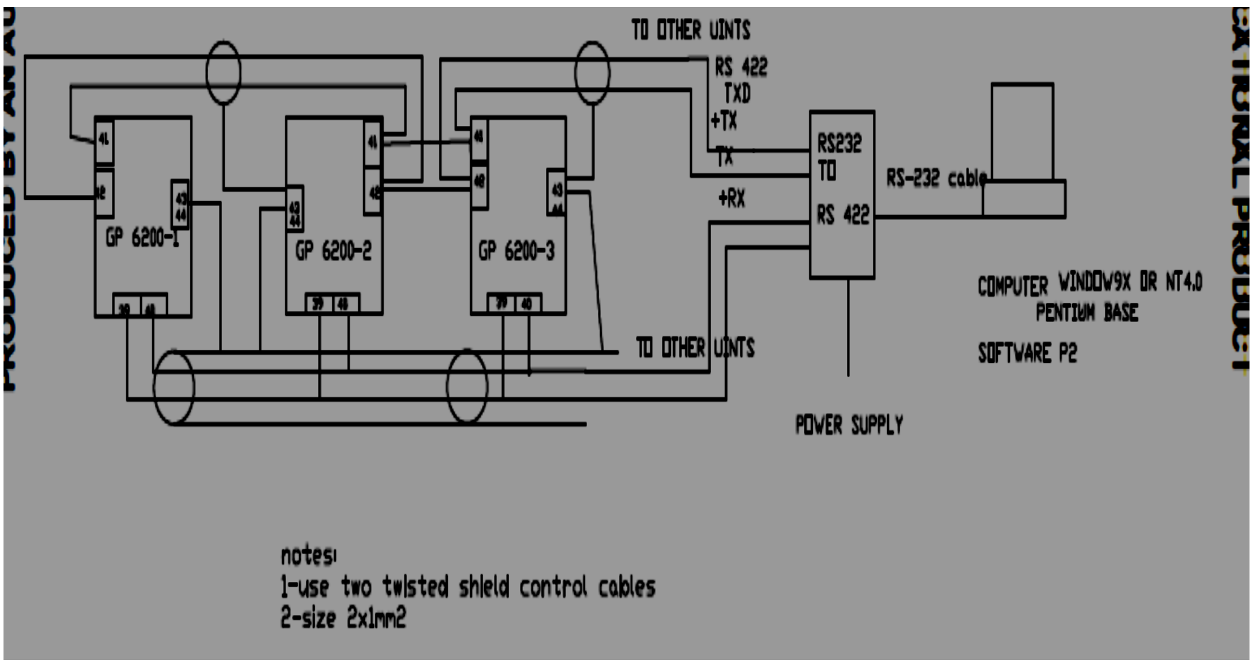

Figure 7 RS-422 network for monitoring

9 configuration

the 6200 control panels were configured to achieve standby isolanding operation mode with generator no .2 as the master the menus are :

-configuration menu
-shut down and alarm

-engine control

-synchronizing

-real load control

-reactive load control

-sequences and communication

-calibration

Tunned data where choosing during parallel operation tests with real load mainly motors.

table 2 shows setting values for load sharing menu

Table 2 load sharing menu

item	Parameter	function	setting
1	Load control mode		normal
2	Load control gain	In parallel with mains	Not required
3	Load share gain	Gain of sharing controller	0.8
4	Load stability	Integration remove the error	2.0 sec
5	Load derivative	Active in load ramping, and transient	0.2 sec
6	Load control filter	Low pass filter for transients Suppression ,active in load sharing	1.0 HZ

7	Un load trip	Load level where generator breaker open command issued	5% of power rated
8	Load droop	Load percentage droop	In droop mode
9	Load time	Time from unload trip to base load ramping	10 SEC
10	Unload time	Time for unloading from base load to unload limit	10 SEC
11	Raise load rate	In base load	2.00%/SEC
12	Lower load rate	In base load	2.00%/SEC
13	Generator load high limit	Prevent over load	85%
14	Generator high alarm	delay	warning
15	Generator load low limit	Prevents reverse current	10%

16	**Low load limit alarm**	**Delay for min load**	**warning**

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Appendix A:F.G.Wilson generator data sheet

P2000/P2200E

Image for illustration purposes only.

Output Ratings

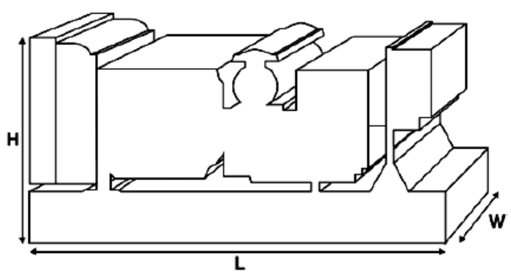
Generating Set Model	Prime*	Standby*
380-415V,50Hz	2000.0 kVA / 1600.0 kW	2200.0 kVA / 1760.0 kW
	- / -	- / -

Ratings at 0.8 power factor.

Prime Rating
These ratings are applicable for supplying continuous electrical power (at variable load) in lieu of commercially purchased power. There is no limitation to the annual hours of operation and this model can supply 10% overload power for 1 hour in 12 hours.

Standby Rating
These ratings are applicable for supplying continuous electrical power (at variable load) in the event of a utility power failure. No overload is permitted on these ratings. The alternator on this model is peak continuous rated (as defined in ISO 8528-3).

Standard Reference Conditions
Note: Standard reference conditions 25°C (77°F) Air Inlet Temp, 100m (328 ft) A.S.L. 30% relative humidity.
Fuel consumption data at full load with diesel fuel with specific gravity of 0.85 and conforming to BS2869: 1998, Class A2.



Ratings and Performance Data

Engine Make & Model:	Perkins 4016TAG2A	
Alternator manufactured for FG Wilson by:	Leroy Somer	
Alternator Model:	LL9124H	
Control Panel:	PowerWizard 1.1+	
Base Frame:	Heavy Duty Fabricated Steel	
Circuit Breaker Type:	3 Pole ACB	
Frequency:	**50 Hz**	**60 Hz**
Engine Speed: RPM	1500	-
Fuel Tank Capacity: litres (US gal)		-
Fuel Consumption: l/hr (US gal/hr)		
(100% Load) **- Prime**	423.5 (111.9)	-
- Standby	474.1 (125.2)	-

Available Options

FG Wilson offer a range of optional features to tailor our generating sets to meet your power needs. Options include:

- Upgrade to CE Certification
- A wide range of Sound Attenuated Enclosures
- A variety of generating set control and synchronising panels
- Additional alarms and shutdowns
- A selection of exhaust silencer noise levels

For further information on all of the standard and optional features accompanying this product please contact your local Dealer or visit: www.FGWilson.com

Dimensions and Weights

Length (L) mm (in)	Width (W) mm (in)	Height (H) mm (in)	Dry kg (lb)	Wet kg (lb)
5749 (226.3)	2300 (90.6)	3020 (118.9)	15495 (34161	15695 (34602

Dry = With Lube Oil   Wet = With Lube Oil and Coolant

Ratings in accordance with ISO 8528, ISO 3046, IEC 60034, BS5000 and NEMA MG-1/22.
Generating set pictured may include optional accessories.

FG Wilson has manufacturing facilities in the following locations:
Northern Ireland • Brazil • China • India • USA
With headquarters in Northern Ireland, FG Wilson operates through a Global Dealer Network.
To contact your local Sales Office please visit the FG Wilson website at www.FGWilson.com

Engine Technical Data		
No. of Cylinders / Alignment:		16 / Vee
Cycle:		4 Stroke
Bore / Stroke: mm (in)		160.0 (6.3)/190.0 (7.5)
Induction:		Turbocharged Air To Air Charge Cooled
Cooling Method:		Water
Governing Type:		Electronic
Governing Class:		ISO 8528 G2
Compression Ratio:		13.6:1
Displacement: l (cu. in)		61.1 (3730.0)
Moment of Inertia: kg m² (lb/in²)		20.72 (70803)
Engine Electrical System:		
	- Voltage / Ground	24/Negative
	- Battery Charger Amps	40
Weight: kg (lb)	- Dry	5570 (12280)
	- Wet	5847 (12890)

Performance		50 Hz	60 Hz
Engine Speed: rpm		1500	-
Gross Engine Power: kW (hp)			
	- Prime	1766.0 (2368.2	-
	- Standby	1937.0 (2597.6	-
BMEP: kPa (psi)			
	- Prime	2311.1 (335.2)	-
	- Standby	2535.2 (367.7)	-

Fuel System	
Fuel Filter Type:	Replaceable Element
Recommended Fuel:	Class A2 Diesel
Fuel Consumption: l/hr (US gal/hr)	

Prime	110% Load	100% Load	75% Load	50% Load
50 Hz	474.1 (125.2)	423.5 (111.9)	312.9 (82.7)	212.9 (56.2)
60 Hz	-	-	-	-

Standby	110% Load	100% Load	75% Load	50% Load
50 Hz		474.1 (125.2)	344.9 (91.1)	232.1 (61.3)
60 Hz		-	-	-

(Based on diesel fuel with a specific gravity of 0.84 and conforming to BS2869, Class A2)

Air Systems		50 Hz	60 Hz
Air Filter Type:		Replaceable Element	
Combustion Air Flow: m³/min (cfm)			
	- Prime	137.0 (4838)	-
	- Standby	145.0 (5121)	-
Max. Combustion Air Intate Restriction: kPa (in H_2O)		3.7 (14.9)	-

Cooling System		50 Hz	60 Hz
Cooling System Capacity: l (US gal)		355.0 (93.8)	-
Water Pump Type:		Centrifugal	
Heat Rejected to Water & Lube Oil:			
kW (Btu/min)	- Prime	660.0 (37534)	-
	- Standby	721.0 (41003)	-
Heat Radiation to Room: Heat radiated from engine and alternator			
kW (Btu/min)	- Prime	200.1 (11379)	-
	- Standby	231.0 (13137)	-
Radiator Fan Load: kW (hp)		63.5 (85.2)	-
Radiator Cooling Airflow: m³/min (cfm)		2058.0 (72678)	-
External Restriction to Cooling Airflow: Pa (in H_2O)		250 (1.0)	-

Designed to operate in ambient conditions up to 50°C (122°F).
Contact your local FG Wilson Dealer for power ratings at specific site conditions.

Lubrication System	
Oil Filter Type:	Spin-On, Full Flow
Total Oil Capacity: l (US gal)	238.0 (62.9)
Oil Pan: l (US gal)	214.0 (56.5)
Oil Type:	API CG4 15W-40
Oil Cooling Method:	Water

Exhaust System		50 Hz	60 Hz
Silencer Type:		Optional	
Silencer Model & Quantity:		- (-)	
Pressure Drop Across Silencer System: kPa (in Hg)		-	-
Silencer Noise Reduction Level: dB		17	-
Maximum Allowable Back Pressure: kPa (in Hg)		6.6 (1.9)	-
Exhaust Gas Flow: m³/min (cfm)			
	- Prime	387.0 (13667)	-
	- Standby	387.0 (13667)	-
Exhaust Gas Temperature: °C (°F)			
	- Prime	493 (919)	-
	- Standby	493 (919)	-

Alternator Physical Data	
Manufactured for FG Wilson by:	Leroy Somer
Model:	LL9124H
No. of Bearings:	1
Insulation Class:	H
Winding Pitch Code:	2/3 - 6S
Wires:	6
Ingress Protection Rating:	IP23
Excitation System:	AREP
AVR Model:	R449

Alternator Operating Data	
Overspeed: rpm	2250
Voltage Reguation: (Steady state)	+/- 0.5
Wave Form NEMA = TIF:	50
Wave Form IEC = THF:	2.0%
Total Harmonic content LL/LN:	2.5%
Radio Interference:	Suppression is in line with European Standard EN61000-6
Radiant Heat: kW (Btu/min)	
- 50 Hz	81.0 (4606)
- 60 Hz	-

Alternator Performance Data:	50 Hz			60 Hz
Data Item	415/240V	400/230V	380/220V	
Motor Starting Capability* kVA	6986	6509	5897	
Short Circuit Capacity** %	300	300	300	
Reactances: Per Unit				
Xd	3.230	3.480	3.850	
X'd	0.240	0.260	0.290	
X"d	0.126	0.136	0.151	

Reactances shown are applicable to prime ratings.
*Based on 30% voltage dip at 0.6 power factor.
**With optional permanent magnet generator or AREP excitation.

Voltage Technical Data 50 Hz				
Voltage	Prime:		Standby:	
	kVA	kW	kVA	kW
415/240V	2000.0	1600.0	2200.0	1760.0
400/230V	2000.0	1600.0	2200.0	1760.0
380/220V	2000.0	1600.0	2200.0	1760.0

Voltage Technical Data 60 Hz				
Voltage	Prime:		Standby:	
	kVA	kW	kVA	kW