Generator Technologies

Application Guidance Notes: Technical Information from Cummins Alternator Technologies

AGN 154 - Single Phase Loading for Re-Connectable 3-Phase Windings

TECHNICAL OVERVIEW

It must be accepted; when reconnecting a 3-phase 12-wire winding for a single phase output, the alternator's output rating will be less than it is for a 3-phase output. There are variations in the single phase electrical supply that is available and these are explain below. There are a number of other considerations that must be taken into account and these form an important part of this technical overview.

Electrical

When a three phase stator is supporting a balanced 3-phase load, the magnetic flux resulting from current flowing in the Stator windings (armature reaction) is a balanced 3-phase flux rotating in synchronism with the main field (rotor). Therefore, a steady and balanced level of magnetic flux crosses the stator-to-rotor air gap and as a consequence, negligible voltage is induced in the rotor's damper cage windings.

When the same stator is used to supply an unbalanced 3-phase load, or has its windings reconnected (Zig Zag, Double Delta or Edison Delta) to provide a dedicated single phase output voltage, then the above described balanced magnetic flux across the air gap no longer exists.

Remember; each section of winding will always have induced voltages in accordance with the 3-phase principle of U, V, W with 120° displacement. Therefore, when the stator windings are reconnected in order to support a single phase load, the winding sections become forced to operate in an 'uncomfortable' mode of operation created by the current flow through each winding section, which will no longer be either balanced in magnitude, or have the same phase angle relationship when compared to the induced voltage – in each phase – but must align with the resultant single phase load current flowing shared by all sections of winding.

This results in each section of the stator winding having a different level of load current and associated current phase angle displacement. Each winding section will have a different level of 'armature reaction', which creates a complex de-magnetising effect of the rotor pole flux and this will result in a pulsating air gap flux. Consequently, the damper cage is now subjected to a contra rotating flux, which induces a continuous condition of pulsating magnitude of voltage to be induced into the rotor's damper cage and so, a resulting similar characteristic current will flow within the rotor's damper cage assembly.

The damper cage has a designed limit for operating with current flow and related duration, which is technically described as being its I^2t rating. **Therefore, it is necessary to very carefully consider any proposed single phase loading condition against the design limit for the design of the alternator's damper cage.**

The functional criterion for a damper cage is complex and so, this AGN will not enter into all such technical aspects other than the fundamental functions of providing oscillatory damping of rotor load angle changes and thereby, assisting system stability after load step changes or, when alternators are operating in parallel. Its ability to cope with unbalanced load conditions is always, a quite secondary consideration for a cost effect high volume manufactured alternator.

Therefore, damper cage design considerations take into account the likelihood of the alternator being operated under unbalanced load conditions. These subjective considerations direct the designers of the STAMFORD alternators to expect alternators up to 200kVA, to be subjected to unbalanced load conditions. The damper cage has been designed accordingly.

As alternator size increases, it is considered that this range of alternators are far less likely to be subjected to unbalanced three phase loads and reconnection to provide a dedicated single phase output is just not even provided as an option. Correspondingly, the damper cage design becomes more focussed on principal modes of operation.

Mechanical

When an alternator is supplying an unbalanced 3-phase load or has been reconnected to give a dedicated single phase output, there will be a pulsating load across the stator-to-rotor air gap as explained above. This pulsating (load) torque will increase the operational vibration levels of the Generating Set; a 'rule of thumb' value is that an increase of some 25% will be observed. The mechanical drive line will also be subjected to the pulsating torque and so should be engineered appropriately.

Output Cable Connections

Any alternator re-connected to provide a dedicated single phase output will now provide an electrical output at a much higher current rating than the normal 3-phase output. This will require the Generating Set manufacturer to very carefully consider the physical size of the proposed output conductors and thereby, careful consideration with regard to how an appropriately rated conductor can be connected to the standard alternator terminal assembly. Here, identifying the available surface area of the available contact patch and a method for supporting the weight of the proposed output conductors will need very careful consideration.

Practical Consideration

This change in design policy with larger alternators, coupled with the fact that kVA output and thus, armature reaction increase approximately as the cube of diameter with increasing alternator size, results in a decreasing cross sectional area of damper winding relative to armature reaction. This is a short term function and thermal capacity of the windings is low priority.

Single Phase Output as a percentage of the 3-phase output.

The following list provides guidance of the re-rate factor across the STAMFORD range, from simply considering the effects on damper cage capability.

Alternator Type	Single phase output as a % of 3-phase output (Class H)
S0 / S1	58%
P0 / P1	58%
UC 224 (S2)	67%
UC 274 (S3)	60%
S4	50%
HC5 (S5)	40%*****
S6	Do not offer
P7 (S7)	Do not offer

Note ***** The terminal arrangement on the HC5 (S5) alternator models is not conducive to reconnecting for a single phase output.

UNBALANCED LOADS ACROSS A THREE PHASE WINDING

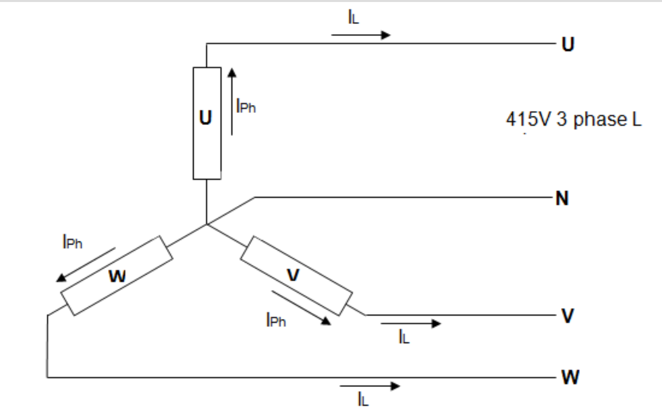
This section covers the available output from the various terminal connection options, always using the standard 12-wire re-connectable winding option to provide examples. The first two examples show a balanced 3-phase load condition as reference for the later shown schemes.

Star Connection

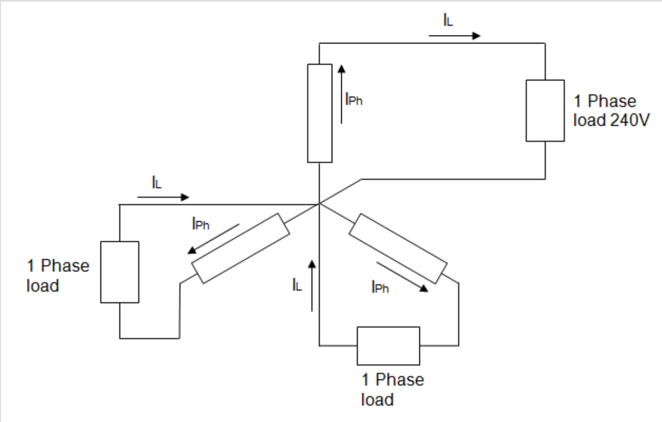
Case A – 3-Phase Output

3-Phase output at 415V / 240V

$I_{Ph} = I_L = 100A$
Alternator rating for 3 Phase = 71.9kVA



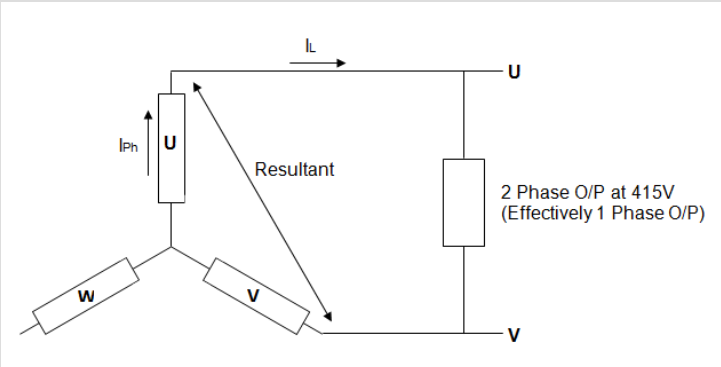
Case B – 3 Individual Single Phase Outputs



$I_{ph} = I_L$ = 100A for each phase
= 240V x 100A (each phase) = 24kVA

Alternator total rating = 24 + 24 + 24 = 72kVA

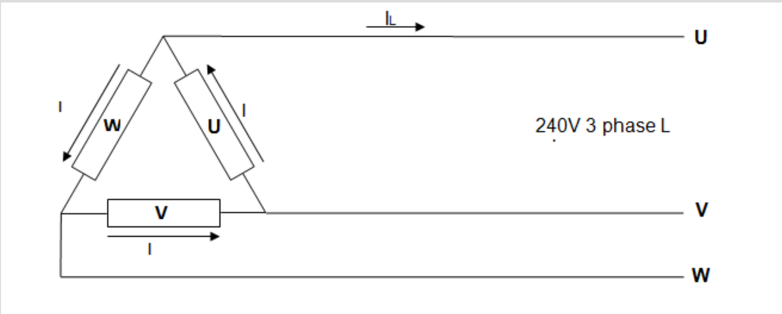
Case C – 2-Phase Output (effectively Single Phase Output)



Because the effectively Single Phase load is being 'driven' by a resultant voltage and therefore, the load current is out of phase with the generated phase voltages, the I_L must be reduced to 75% of I_{Ph}. So, I_L will be 75A, Voltage will be 415V.

Delta Connection

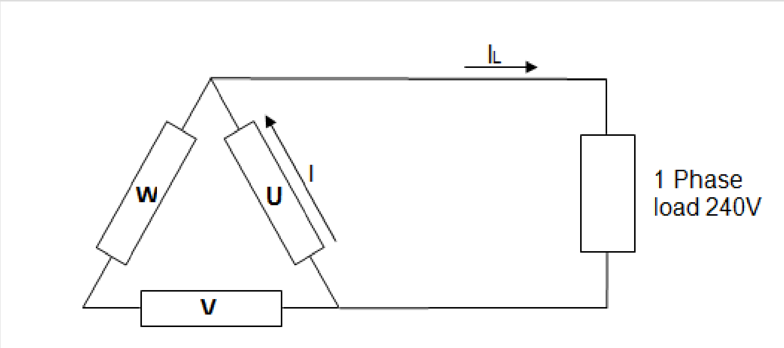
Case A – 3-Phase Output, 240 L-L



$I_L = \sqrt{3}\, I_{wdg}$
$I_{ph} = 100A$
$I_L = 173.2A$

Alternator rating for 3 Phase = 71.9kVA

Case B - Single Phase Delta Connected



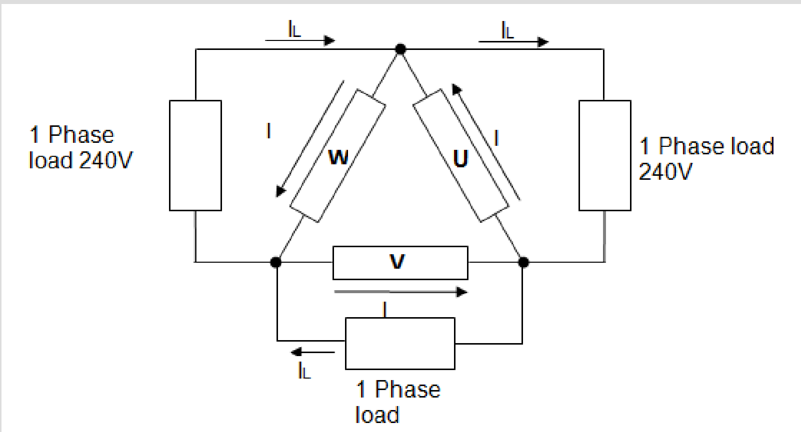
Classic Single Phase rating factor is 0.67, but this does vary as follows:

S0/S1 = 58%
P0/P1 = 58%
UC 224 (S2) = 67%
UC 274 (S3) = 60%
S4 = 50%
HC5 (S5) = 40%

For example: UC 224 (S2):

71.9kVA x 0.67 = 48kVA
I_L = 200A, and I_{ph} = 100A

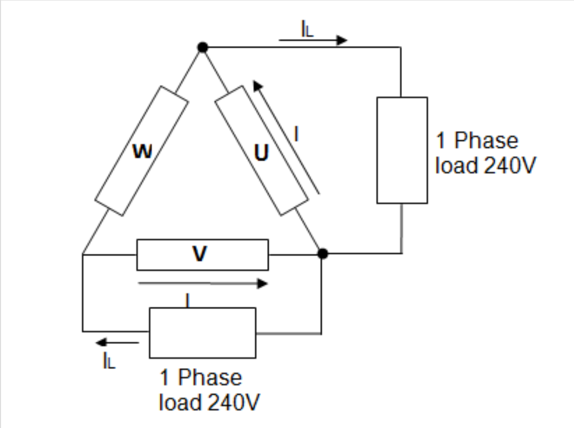
Case C – 3-Phase Delta Connected - 3 individual Single Phase Outputs



$I_{wdg} = I_L$ = 100A for each phase
= 240V X 100A (1 phase) = 24kVA

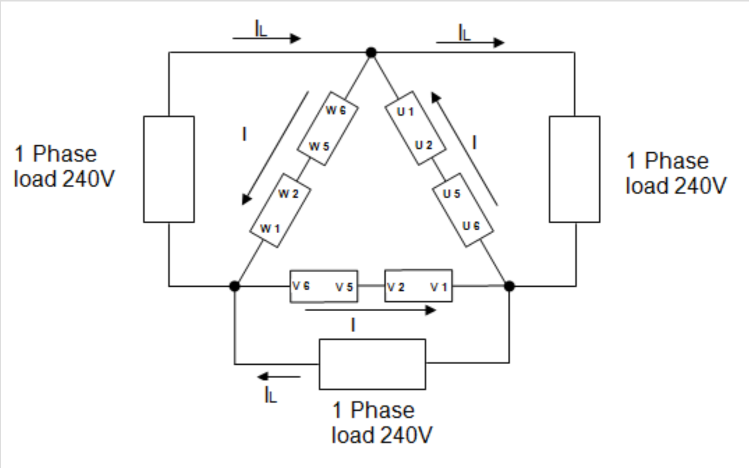
Alternator total rating = 24 + 24 + 24 = 72kVA

Case D – 3-Phase Delta Connected – 2 individual Single Phase Outputs



Each Single Phase load can be 240V X 100A = 24kVA

Case E - Series Delta Connected



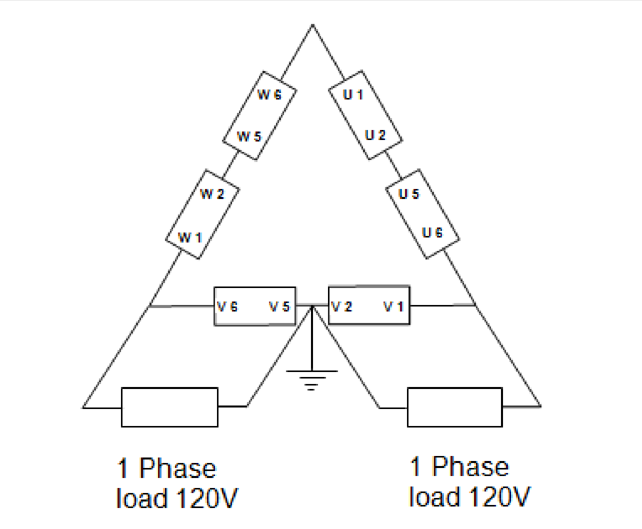
I_{wdg} = I_L = 100A for each phase
= 240V X 100A (1 phase) = 24kVA

Alternator total rating = 24 + 24 + 24 = 72kVA

Case F – Edison Delta Connected

The Edison Delta 3-phase connection could also include some 120V 1-Phase; however, once the windings in the base of the Edison Delta triangle start to provide 1-Phase at 120V, these windings have to be now operated with less 3-Phase current.

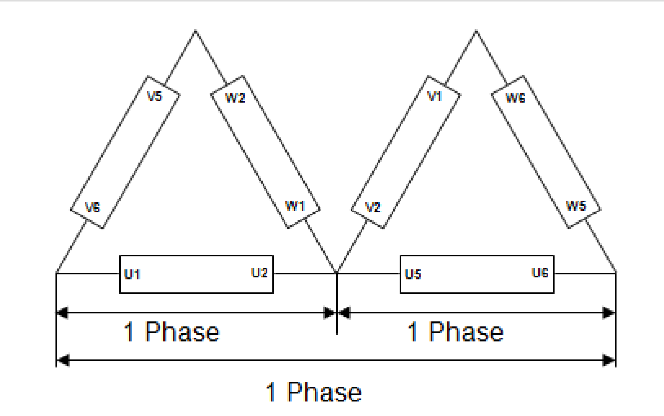
Total current in the base windings must never exceed design level, which is 100A for each phase. Remember that In Delta, where there are Parallel circuits (which there are not in Star) the output current at 240V, 3-Phase is $\sqrt{3}$ X 100A = 173.2A.



Therefore; as soon as 120V at 100A (12kVA) is being taken from one of the 110V 1-Phase outputs, there is no capability for any 3-Phase output. True, there are the other 120V 1-Phase outputs, which could also provide some 12kVA, but these must remain two individual separate outputs.

True again, that the two sides of the Delta triangle could be used for individual 240V 1-Phase outputs, but again the limit is the phase current of 100A; therefore 240V x 100A = 24kVA. This combination of 240V 3-Phase, 240V 1-Phase and 120V 1-Phase requires very careful control by circuit breakers and current detection.

Case G - Dedicated Single Phase (Double Delta)



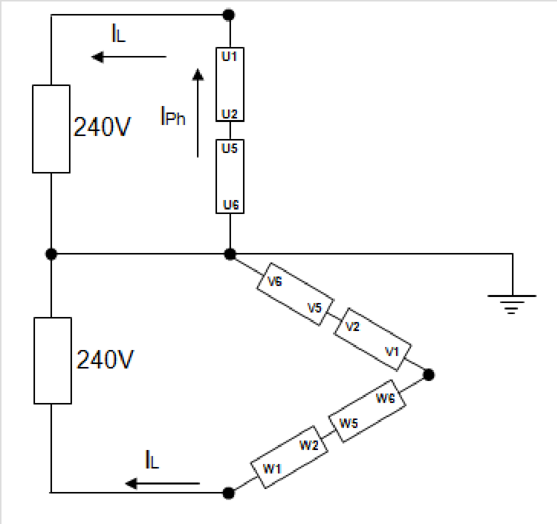
The Double Delta connection is commonly used to utilise a 3-phase winding for a single phase output. This reconnection provides the possibility of a mix of 240V and 120V outputs simultaneously, but the current through the bottom leg when 240V and 120V are being taken, must not exceed the total current of 200A (48kVA / 240V). In effect, the Double Delta connection gives a 4 wire single phase system. Windings 1 – 5 and 2 – 6 can be paralleled to give the full 48kVA (200A) at 120V.

Series Zig-Zag Connection

Often known as a ‘rural supply’, the Series Zig-Zag connection offers a 400V to 480V, 50Hz supply, which is sometimes divided to provide 240V 50Hz; used typically for supplying domestic properties in isolated areas. This is known as ‘split phase’ and is achieved by using each 240V tapping point. Split phase supplies have the potential of unbalanced loads, as this would be dependent on load requirements in the area at the time when the alternator is operating.

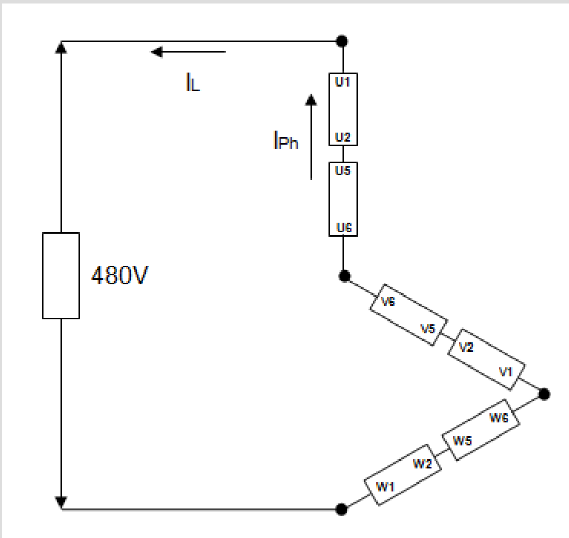
A 480/240V, 3 wire, rural supply, can be supplied from the standard Winding 311, by connecting into series zig-zag as shown in the following drawing:

Case A - Supporting two single loads



Supporting two individual single phase loads
Each load = 240V X 100A = 24kVA

Case B - Single Phase Load



Supporting one individual 480V single phase load, because the effectively 1-Phase load is being ‘driven’ by a resultant voltage and therefore the load current is out of phase with the generated phase voltages, the I_L must be reduced to 75% of I_{wdg}.

So, I_L will be 75A, Voltage will be 480V and kVA = 480V X 75A = 36kVA.

Application Engineering may be contacted on applications@cummins.com to assist with reconnection options and rating caculations.

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