STAMFORD | AvK ™

POWERING TOMORROW, TOGETHER

Application Guidance Notes: Technical Information from STAMFORD | AvK

AGN 003 – Transient Performance and Locked Rotor Curves

TRANSIENT PERFORMANCE

There follows, a simplified explanation of the Transient Voltage Dip (TVD) behaviour of an alternator. It starts from an assumption that the alternator is operating at rated voltage and then a block load is suddenly applied.

The initial part of the voltage dip is a product of the alternator's reactances, both sub-transient (X"d) and transient (X'd), along with other subtle considerations that are combined to become a mathematical tool, as is - in the form of all reactances - called Xg.

Imagine the output voltage as a recorded trace in the form of 100% volts being a straight, horizontal line. When a load is suddenly applied, the output voltage level will fall and so the horizontal trace will now show a rapidly falling characteristic. The 'angle' of the trace line depicting the falling voltage becomes arrested and is changed to a more gentle gradient (but still a falling trace) by the ability of the AVR's response characteristic to 'force' the excitation system to begin to capture the falling voltage and then to force the alternator's output voltage upwards, back towards the 100% 'set-level' by increasing the alternator's excitation level.

The very initial increase in excitation current merely changes the falling voltage into an **L** shape, where the base of the **L** may still be pointing slightly downwards. As the excitation is further increased the **L** starts to become a **U** shape as the volts are pushed back upwards towards the 100% nominal voltage level.

In a real simple approach to the problem, where it can be assumed that the engine **is** capable of maintaining absolute continuous rated speed (with no deviation from nominal), results in a situation, whereby the only restraint to getting the alternator's output voltage back up to the 100% nominal is that associated with how hard the AVR can push the excitation system and so, in turn, restore the ideal operating magnetic flux levels associated with the supporting 100% output voltage, whilst supporting the load's kVA demand.

Now we can simplify the situation about how hard the AVR can 'push', by considering the available pushing-power, in terms of the available AVR power supply voltage level. The phrase commonly used to identify this available voltage is "excitation system ceiling voltage".

The excitation system used on STAMFORD separately-excited alternators and some AvK alternators incorporates a Permanent Magnet Generator (PMG) to power the Digital AVR or Analogue AVR. The Digital AVR has a ceiling voltage of 250V and the Analogue MX type AVR has a ceiling voltage of 120V.

The Analogue AVRs used on STAMFORD self-excited alternators are powered by a fixed proportion of the alternator's output voltage level and if this has suddenly fallen under the effect of the impact load, then the available voltage to the AVR's power circuit will be reduced, in turn resulting in a reduction of the available 'forcing' voltage. Therefore, inevitably resulting in a greater level of TVD%.

The level of TVD% is shown on the Locked Rotor Curve for each alternator, published in the Technical Data Sheet.

Consider that under the normal full-load, rated kVA and power factor conditions, the level of alternator excitation voltage is typically:

S0/S1, P0/P1 & UC = <40V, S4 & HC5 (S5) = <50V, S6 & P7 (S7) = <60V, S9 = <70V

It can therefore be appreciated that the 'forcing capability' of the 'ceiling voltage' is a factor of at least twice that of the nominal Full-Load excitation level. Under the No-Load conditions, with excitation voltage levels of typically only 10V, then this factor is typically ten times.

The above identifies the means (power) available to the AVR to force the excitation system to respond and so restore the alternator's output voltage to 100% nominal after any impact load step. Also, an appreciation of the mechanism involved for restoring the alternator's output voltage to nominal 100% and the benefits of systems with different sources of power supply to the AVR.

Now, even with this *special* constant speed engine, the return to nominal V will not be instantaneous, because the magnetics within the exciter and main rotor are *SLOW* and so the restoration to 100% volts will appear as a trace with a gradient.

Unfortunately, the AVR will 'push' hard enough to actually force the voltage above the nominal 100%, a condition instantly recognised by the AVR and so now begins a process involving a delay waiting for the over excitation to decay. Remember AVR's are designed to 'blow'; they have no ability to 'suck' away excess excitation.

Over a period of about 0.6sec the output voltage ‘rings’ around the 100% level and then settles out at the ‘set’ nominal level.

The engine will lose speed. The level of speed reduction, combined with the rate of speed reduction will detrimentally affect the above described ‘ideal’ minimum level of output voltage TVD%. Typically, a 2% loss in engine speed will result in an extra ‘straight’ 1% being added to the alternator’s TVD% level, as indicated by the alternator’s Locked Rotor Curve data sheet.

The situation of attempting to predict the actual level of TVD% for the generating set becomes even more difficult if the loss of speed is sufficient to activate the AVR’s Under Frequency Roll Off (UFRO) protection circuit, which is designed to reduce the output voltage if an under speed running condition occurs.
The UFRO system is actually able to assist an engine to accept a high kVA load step by reducing the alternator’s output voltage when the load step results in such a demand for engine power is such that rated speed cannot be maintained.

Such a situation can be assisted by making use of the UFRO setting of the AVR as this will help the engine accept the block load step. This is because if the alternator output voltage is reduced, then the current demanded by the load will be reduced and with lower V & I, the actual block load kVA is reduced. This, in turn, reduces the instant demand for engine power and helps by not forcing the engine speed down to the level that would have resulted if the load kVA had not been reduced.

Once the AVR’s UFRO circuit has been activated then the system TVD% will be increased and so too will be the recovery time, because now the AVR will not immediately try to force the output voltage back to 100% nominal, but only to a reduced voltage level set by the AVR’s UFRO settings.

On the MX type of AVR, the rate at which voltage falls with speed can be set by the DIP potentiometer. On the MX321 AVR, there is a further adjustment available from the DWELL potentiometer, which will adjust the rate at which the voltage will be restored to nominal 100%, in proportion with engine speed returning to nominal 100%.

It should now be apparent that if an engine will be unable to maintain driven speed during a block load application and the speed of the generating set falls below 96% of nominal and so activating the AVR’s UFRO circuit, then the resulting TVD% can only be established by actual load acceptance testing of the complete generating set.

LOCKED ROTOR CURVES

The Locked Rotor Curves are used as a guide to indicate the expected transient voltage dip/rise upon impact/rejection of load.

The curves are based on results from tests conducted in accordance with the requirements of **IEC 60034** and therefore the alternator’s performance was measured with the alternator operating at a constant nominal design related speed.

The factors which govern the transient load step performance of an alternator are complex but can be primarily related to the sub-transient and transient reactances. The values assigned to these reactances are subject to a tolerance band of +/-30% (source **IEC 60034-1 Edition 13.0 Dated 2017-05, Table 21 Item 16**) and so the load step performance between different alternators can be subject to a degree of variability.

Once the alternator has been incorporated within a generating set, where undeniably the prime mover will NOT maintain constant speed during a load step condition, then the performance data provided by the alternator manufacturer will not be achievable.

Furthermore, the real world associated with motor starting, magnetising transformers, etc., inevitably introduces a degree of variability regarding the precise phase angle displacement and so cumulative value of applied lagging power factor (PF) of the total load which will naturally include the impedance of the associated distribution system.

TRANSIENT VOLTAGE DIP WITH LOAD APPLICATION

The alternator's behaviour under a sudden step load and the resulting TVD is of particular interest under low power factor load conditions, typically starting motors. Therefore, the provided curves are based on relatively low power factors, typically in the region of 0.2 PF lagging. The degree of voltage dip reduces as the power factor of the applied load increases towards unity PF The following scaling factors offer general guidance, although it must always be remembered that using such factors will provide a good guide rather than an empirically absolute value.

Lagging Power Factor	Scaling Factor
<=0.4	1.00
0.5	0.95
0.6	0.90
0.7	0.86
0.8	0.83
0.9	0.75
1.0	0.65

As general guidance it can be assumed that typically, there is an additional 1% TVD for each 2% speed drop, provided the AVR's inherent control function associated with Under Frequency Roll Off (UFRO) circuit has not been triggered to operate.

TRANSIENT VOLTAGE RISE WITH LOAD REJECTION

A voltage rise or overshoot occurs upon removal of electrical load. Here mainly loads between 0.7 PF and unity power factor will be of interest and for these conditions the level of Transient Voltage Rise (TVR%) can be taken as a direct % value read from the curves – but as TVR rather than a TVD. The following scaling factors should be applied for loads with a lagging pf of less than 0.7.

Lagging Power Factor	Scaling Factor
<=0.4	1.25
0.5	1.20
0.6	1.15
0.7	1.10
>0.7	1.00

It must be remembered that immediately following the moment of load rejection, there is a prevailing excessive level of excitation which takes a finite time to decay and the excitation level to be stabilise to rated voltage. The lower the flux level, the higher the TVR and longer the "settling" time to no load voltage level.

The above factors can only be used for alternators which are operating close to their ‘ideal’ flux levels. An example of an alternator NOT working close to its ‘ideal’ flux level would be a winding 311/312 operating at 380V, 60Hz.

STANDING / BASE LOADS

Any standing/base load being supported by the alternator may affect the voltage dip and recovery performance of a generating set if the next load to be applied is a motor start situation and the cumulative total demand for engine power exceeds the engine’s capability. For this reason a Load Diagram for the proposed scenario should be created by the engineer responsible for determining the performance of the generating set when considering its capability to meet the expectations of the proposed electrical loads.

VOLTAGE DIP & RECOVERY CURVES

Unfortunately, it is impractical and would indeed be a waste of resources for CGT to record the recovery trace for each individual alternator. Instead, only the voltage dip with respect to impact kVA is recorded for each individual alternator - see test procedure **ER162**.

However, within our test procedures we have embedded a general statement of compliance which all our alternators must meet. This states that ‘the voltage will recover within 97% of the nominal voltage within 300mS’.

If further proof of the recovery time is required specific tests **ER160** and **ER161** could be selected when purchasing the alternator. Please contact our contracts department for the prices associated with these tests.

TECHNICAL POINTS WORTH CONSIDERING

With a static load (resistive), the current drawn will reduce linearly and instantaneously in direct sympathy with the applied voltage. Such behaviour assists a generating set to accept load, because if there is a significant transient dip of both Voltage and Frequency, then the level of supplied kW is reduced.

Dynamic loads, such as induction motors, have an inverse current characteristic. Should the Voltage and Frequency of any already running electric motors momentarily dip, those motors need to re-accelerate by drawing more current from the generating set. This has the effect of amplifying the resulting TVD and delaying the return to normal rated Voltage and Frequency.

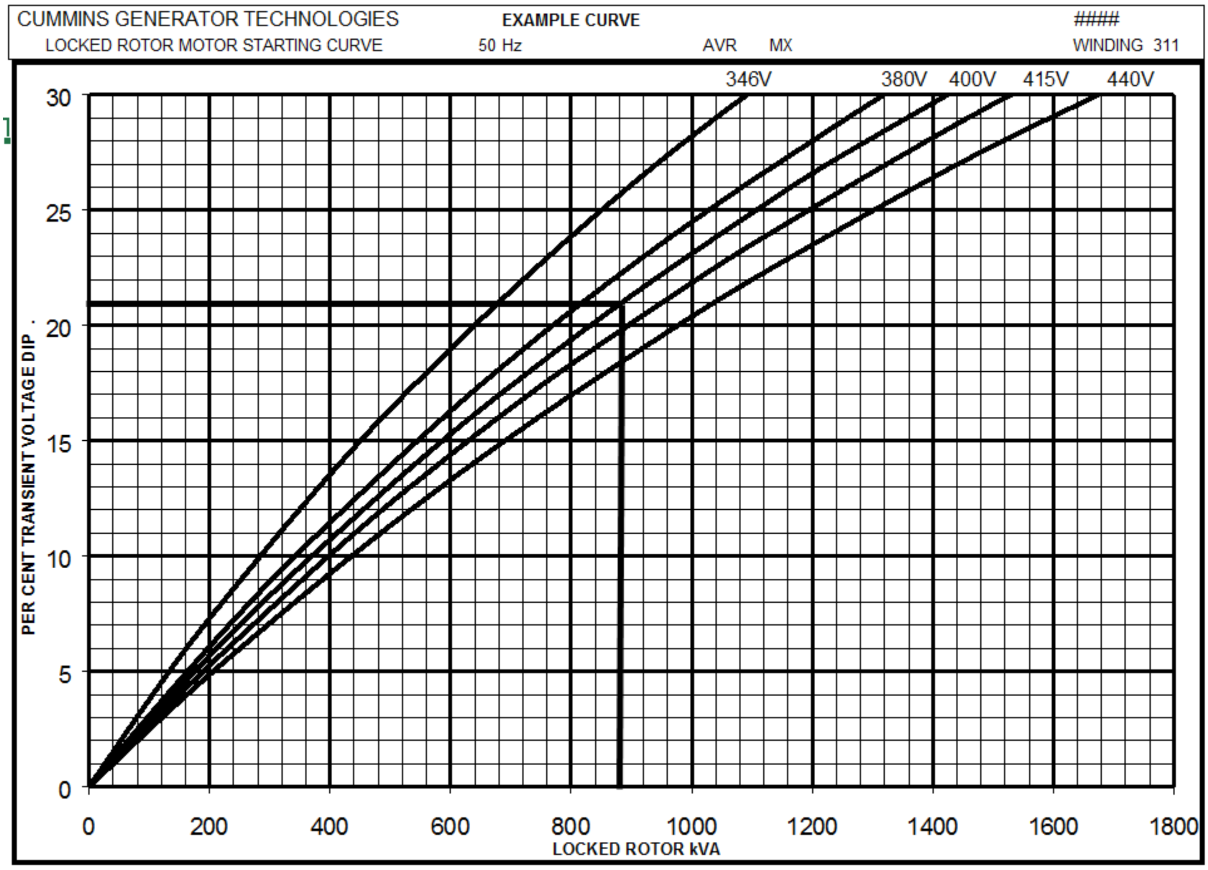
EXAMPLE – TRANSIENT VOLTAGE DIP

The example on the following page is for a motor starting impact load of 880kVA at 400V 50Hz and a power factor of 0.5 lagging.

To determine the expected TVD (at the alternator terminals), the locked rotor value of 880kVA on the bottom axis is projected vertically until it intersects the 400V curve. The corresponding percentage value of TVD is then read from vertical axis (21%).

Referring to the TVD correction factor table on the previous page, it can be seen that the correction factor at 0.5 PF is 0.95. Therefore, 21% x 0.95 = 19.95%

In this case a TVD value of 19.95% is determined.



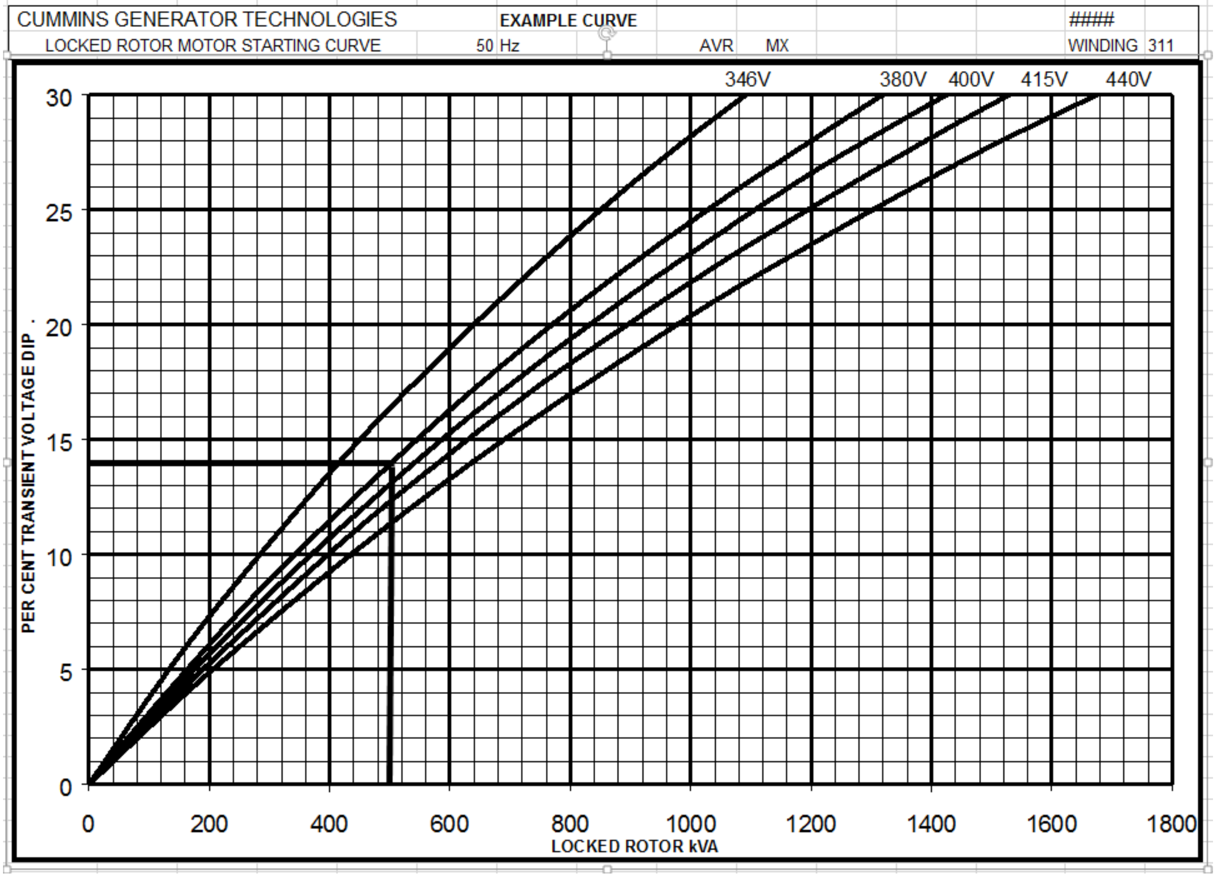
EXAMPLE – TRANSIENT VOLTAGE RISE WITH LOAD REJECTION

The example on the following page is for an alternator is supplying a 500kVA load at 380V 50Hz and a power factor of 0.7 lagging.

To determine the expected TVR (at the alternator terminals), the locked rotor value of 500kVA on the bottom axis is projected vertically until it intersects the 380V curve. The corresponding value of TVR is then read from vertical axis (14%).

Referring to the TVR correction factor table on Page 4, it can be seen that the correction factor at 0.7 P.F. is 1.00. There, no additional correction factor needs to be applied.

In this case a TVR value of 14% is determined.


CUMMINS GENERATOR TECHNOLOGIES
EXAMPLE CURVE
####
LOCKED ROTOR MOTOR STARTING CURVE
50 Hz
AVR
MX
WINDING 311
346V
380V
400V
415V
440V
PER CENT TRANSIENT VOLTAGE DIP
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
1600
1800
LOCKED ROTOR kVA

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