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Application Guidance Notes: Technical Information from STAMFORD | AvK

AGN 068 - Motor Starting and Generating Set Considerations

INTRODUCTION

Begin by considering what happens during a motor start, therefore establishing a level of understanding that will provide confidence to offer a positive route towards nominating a suitable Generating Set for starting and running that motor. To select the correct type and size of alternator, it is necessary to refer to the technical data sheets and associated information manuals that are available from the website. The information included in this Application Guidance Note should be used in conjunction with AGN 090 – Motor Starting Fundamentals and AGN 032 – Motor Starting Methods.

A MOTOR STARTING

Consider an induction motor about to be started. The maximum kVA that will be impacted onto the alternator will be at the instant the supply voltage is applied to the motors terminals. The motor’s rotor is 'locked' at zero speed; therefore, maximum slip frequency and this results in a high level of 'inrush current' to the motors stator windings (there is a resulting high level of current in the rotors cage winding). Just what the motor designer wanted, to ensure the motor develops maximum torque and so, the rotor begins to rotate.

As the rotor speed increases, the rotor slip frequency reduces, resulting in a reduction in the kVAr demanded from the supply (Generating Set) and an increase in kW. The amount of power required depends upon the torque demanded to rotate the motor’s coupled load, but overall, as the speed increases, the motor’s demand for kVA will be reducing. Eventually, the motor reaches rated speed whilst developing duty point power [kWm] as demanded by the motor’s coupled load.

There are considerations to take into account – the unknowns.

- How quickly will the rotor start to turn? This depends on the 'stiction' of the motor's coupled load. This 'static' Locked Rotor condition time period will define the duration of the Locked Rotor condition and most importantly, the duration of the Locked Rotor associated kVA condition, thereby determining the required output characteristics of the alternator. This may well be a severe level of overload and therefore, important data required for the consideration of the resulting magnitude of Transient Voltage Dip (TVD), which will inevitably occur on the system voltage. The magnitude of the TVD% combined with the Locked Rotor up to, say 30% rated speed duration time, combine to have a considerable effect on the time period before the system voltage level is restored to the nominal voltage. The technical considerations here include the ability of the alternator's excitation system - the AVR, exciter and main rotor - to force the alternator's output voltage back to the nominal voltage and restore stability.

- It is important to establish over what time period will the motor's rotor take to accelerate from the Locked Rotor condition up to rated (duty point) speed? The longer the duration of the acceleration period, the longer the motor is in an abnormal condition and consequently, the alternator may also be in an overload condition, and this could be whilst trying to support connected and operating base load equipment.

- For the whole of the start period, the Generating Set is supplying lots of kVA at a low power factor, but this low power factor and high kVA is by no means Wattless. The alternator operating at an overload kVA at a low power factor condition is not exactly operating at a good efficiency, so the demands for engine power begin to build up. This is especially so after the initial mSecs of motor start, once the Generating Set flywheel/rotor kinetic energy has been absorbed and Generating Set shaft speed is now in line with the engine's produced power. Furthermore, as soon as the motor is asked to develop shaft power to turn its coupled load, the demand for real motor (electrical input) power (kW) will have to be satisfied. The motor's input power factor will increase and this total 'real power' has to come from engine cylinder developed BMEP (Break Mean Effective Pressure). The engine's speed recovery capability / load acceptance performance becomes the major issue.

Having thought about what is actually happening with the motor and its load, and the Generating Set, it becomes obvious that the number of identified unknowns outlined above will all combine to affect the motor starting capabilities of a Generating Set.

It is for this reason that STAMFORD | AvK usually comment that the Generating Set manufacturer is the expert in the field of Generating Set capability, in terms of load acceptance and this includes motor starting. We accept that this is a bit of a 'get-out', but on a Generating Set, the performance of the alternator's AVR will be tempered by the AVR's engine relief circuits: The Under-Frequency Roll-Off (UFRO), Voltage Dip (DIP) and dwell (DWELL). So Cummins Generator Technologies data, which always relates to constant speed operation, and a Dynamic AVR with no 'handicap', is not going to be repeated when an engine becomes involved.

RELATIONSHIP BETWEEN MOTOR RATINGS AND GENERATING SET RATINGS

We can now move on to considering the rating of an electric motor, which is 'nameplate' quantified by the developed shaft power, usually in mechanical kiloWatts (kWm) but still sometimes quoted in horsepower (HP).

1 HP = 0.745 kWm
1 kWm = 1.342 HP

As a simply general 'Rule of Thumb' for quick calculation, the motor shaft power in HP = motor full load running kVA at 0.8pf.

Trying to calculate the required continuous Engine kWm of a Generating Set required to run the motor at its maximum continuous rating requires consideration of the motors operating characteristics at full load and rated speed, in the form of efficiency and power factor and then the alternator's efficiency supplying this level of kVA load.

Having established the continuous load for the engine, the start demand of the electric motor must be considered. It is important to establish the motors actual full continuous design 'shaft power' rating, which may be higher than it's on site duty, because when this motor is started it will follow the characteristics of its full design capabilities.

The next vital piece of information is the proposed start method for motor. AGN 090 provides detail of motor starting fundamentals, although we know the starting method is likely to be one of the following:

- Direct on Line (DOL)
- Star - Delta
- Auto-Transformer and %V tap
- Power Electronics Soft Start and % pedestal voltage
- Variable Speed Drive by use of an Inverter

The answers to these considerations will provide guidance of the alternator's task regarding 'inrush kVA' at the instant of initiating the motor start process, which will of course reflect directly onto the Generating Set's engine for driving power.

The start method will also provide guidance about the torque demand of the load being driven by the electric motor, and therefore some insight into the levels and duration of kWm to be provided by the engine.

DOL Start

An electric motor that is being started DOL will be able to develop multiple levels of full load torque – 2, 3 or 4 times depending upon motor design - and it may well be that the motor is being started DOL, because the load coupled to the motor will demand this level of torque in order to drive its coupled load up to speed.

It has to be said that many motors are started DOL simply because it's the most cost effective way to start a motor on a Mains electrical supply. Examples of high starting torque situations are conveyor belt drives, where the conveyor belt is fully loaded with coal or quarry waste, or consider a stone crusher that is being started already full of stone.

Star-Delta Start and Auto-Transformer Start

A motor that is started by the Star-Delta or auto-transformer method will not develop high multiple levels of starting [run-up] torque; therefore will not demand high 'peak' levels of power from the engine.

Usually these start methods are employed where the motor runs up to speed virtually under no-load conditions, the motor load then developing once full running speed has been detected. For instance; Compressors with pressure relief system, or pumps with pipework control valves. However; sometimes these reduced starting current motor start systems are employed because the motor's coupled load is of high inertia - large diameter fan, or a specialist pump - and the system design criteria has been to ramp the motor and coupled load up to speed slowly. Under such applications, the motor will demand an initial torque kick to overcome load 'stiction' and then will rapidly reduce power demand to considerably less than rated power with the real demand for power levels, say levels above 60% of rated power, not occurring until motor speed is above 75% of rated.

It must be appreciated that 'at instant of start' the demand that an electric motor will put onto a Generating Set for kWm may well, for all the reasons explained above, only be present for fractions of a second and therefore, this momentary demand, or kick of power, to start the motor turning may well be satisfied by the kinetic energy of engine flywheel and alternator rotor mass.

Thereafter, the characteristics of the motor start method, the motors design capabilities and the characteristics of the motor's load will combine to set the scale of the real demand placed upon the engine for kWm.

Electronic Soft Start and Variable Speed Drive Start

Starting motors that are under the control of power electronics, either in the form of an Electronic Soft Start or a Variable Speed Drive (VSD) can have their run-up characteristics tailored during commissioning to suit both the motors coupled load expectations and the idealised capabilities of the powering Generating Set.

It is most unusual for VSD systems to demand more than rated power at the initial 'stiction' static/start situation and this will then fall to a sufficient required power level, usually of less than full load / full speed rated power level conditions. The real percentage power level during motor speed acceleration will of course depend upon the characteristics of the motor's coupled load.

Motors being electronic Soft-Started can have their motor static torque developing 'pedestal voltage' adjusted to suit the motor's coupled load requirements and can also have the motor acceleration ramp rate adjusted on site and so achieve a gradual demand for engine power, under controlled, set levels.

Generating Set Engine Power Requirements

Having now covered the all-important motor start methods and offered direction for expectations regarding the engine power delivery, the following are some general 'Rules of Thumb' to assist further in determining the steady state power levels for motors running at full speed / full rated load.

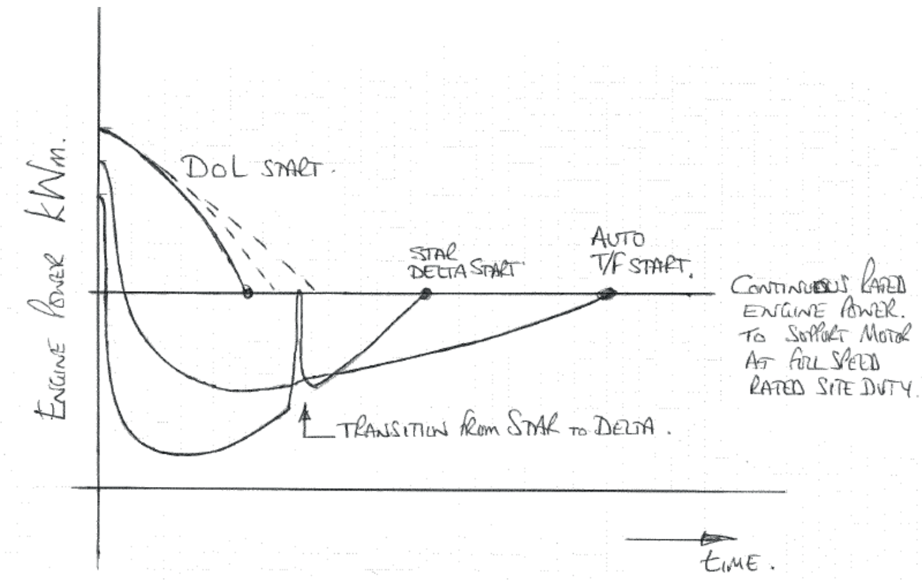
For the minimum engine kWm required:

- Motor kWm x 1.25 = Required Generating Set engine steady state power kWm.

Now consider the engine short term, momentary, peak demand situation. At the instant of motor start:

- DOL Start: Motor kWm.x 2 = Peak demand for Generating Set engine power kWm.
- Auto-Transformer start at 75% Vtap: Motor kWm x 1.8 = Peak demand for Generating Set engine power kWm.
- Star-Delta start: Motor kWm x 1.6 = Peak demand for Generating Set engine power kWm.
- Electronic Soft Start at 40% pedestal Voltage: Motor kWm x 1 = Peak demand for Generating Set engine power kWm.
- Variable Speed Drive: Motor kWm x 1 = Peak demand for Generating Set engine power kWm.

For all the reasons outlined above, the characteristics of the demand for engine power, as the motor accelerates to speed, will set the rate at which the peak demand decays and steady state engine power demand is established. The following graph attempts to show typical characteristics of demand for engine power against time.



ALTERNATOR TECHNICAL DATA

The following summarises tests conducted on STAMFORD and AvK alternators in order to gather appropriate data for inclusion in each alternator's technical data sheet:

- STAMFORD and AvK alternators comply with associated National and International standards that set the rules and expectations for product performance of rotating electrical machines. These standards are all based on the alternator being driven at a constant operating speed throughout the impact load tests.

- For all the reasons previously stated the motor starting tests are conducted at the lowest possible power factor. The STAMFORD and AvK test facilities include a range of induction motors all with their shafts solidly locked to enable a true maximum slip / peak inrush current to occur for a duration period to enable the establishment of the TVD% and the dynamic AVR / excitation behaviour, in order to identify recovery time taken to re-establish nominal Voltage.

- The type of alternator excitation system – Digital, MX, AS or SX – plays an important part in the TVD% and the recovery pattern. The actual machine 'reactance' used is a combination of the sub-transient (X"d) and transient (X'd), plus an excitation component factor, which is grouped together into a factor called **Xg**. Xg is different for every alternator and different at 50Hz and 60 Hz. Xg is simply a calculated test parameter that enables the running of a unique in-house modelling program.

- Using data acquisition equipment, the STAMFORD and AvK based tests follow traceable procedures – IEC60034-1 – to identify the peak TVD for a range of applied impact, low power factor, loads and the results are plotted on to the graphs presented on alternator's technical data sheets as "Locked Rotor Curves".

- The recovery times are difficult to quantify, because the various standards disagree about the point at which recovery / stability is deemed to have occurred. Cummins Generator Technologies do make a claim for the AVR only. The AVR will recover the voltage to within 97% of the nominal voltage within 300mSec. However; this does not allow for the different time constants associated with each different alternator and assumes the simulated motor start condition does not represent more than the rated kVA having been applied to alternator.

MULTIPLE LOADS

Careful consideration should be given to the cumulative load levels whilst supporting established and operating loads and then coping with a motor start situation. Here, the best advice is to create a graphical representation – often called a Load Diagram – which represents kVA (and kW) on the Y axis and elapsed time along the X axis. Hopefully, the motors Locked Rotor condition will not be subjecting the Generating Set to a gross level of overload, resulting in the alternator's excitation system being unable to support that load condition, whilst maintaining rated voltage.

This is the situation when a low impedance fault condition occurs on an electrical system. This results in the excitation system being forced into saturation (flat-out) in order to force current through the low impedance fault at the expense of maintaining rated voltage; where under extreme fault levels, the voltage is virtually zero and all the efforts of the excitation system are spent on forcing an output current and dealing with the stator winding produced armature reaction.

Let's consider a situation where the motor start load results in the Generating Set's output voltage being held down to 90% of rated voltage and this with the AVR / excitation system 'flat-out' on a digital or MX system. Typically, this condition would equate to an output current of 2 x the alternator's designed Class 'H' rated current.

Consider a really 'big' motor start where the Locked Rotor condition equated to 3 x rated current and for alternator's performance guidance, look at a typical Decrement Curve to try to identify alternator performance at virtually constant speed. Just maybe, if the motor Locked Rotor kVA had a duration of some 20mSecs and then the motor could accelerate at a rate such that the inrush did not exceed twice rated kVA for longer than 150mSecs, and achieved rated speed requiring <70% of the Generating Set's designed rating within a total time of 400mSecs; could such a motor start capability be claimed.

Even so, this assumes the engine speed never fell by more than 4% below nominal, thereby the AVR's UFRO circuit was not activated.

SUMMARY

Making claims about a Generating Set's motor starting capability by simply identifying the Motor in terms of shaft kWm is only possible if the motor's start method and the torque expectations of the motor's coupled load are both qualified. This is a 'no win' situation, as the 'end-user' of the motor to be started/run will have little idea of the answers to these two basic questions. We know the Locked Rotor expectations of motors when started by the various methods; DOL, Star / Delta [we also know the pitfall of the peak kVA at Star/Delta transition if this is not correctly set during commissioning], Auto-Transformer, Power Electronic Soft Start [a whole new set of problems - not to be considered here].

The one thing these all have in common is a motor start / Locked Rotor peak kVA impact load, which will be impacted onto the Generating Set. Why not establish the maximum peak kVA impact load, at a low power factor, that the Generating Set can accept within an acceptable TVD% (typically 25%) and state this value in Motor Start kVA.

Then, those wishing to establish that the motor start capability of the Generating Set against their required motor starting duty, can identify the peak inrush for the motor they wish to start by the motor start method they wish to use, because they will [or should know] that their motor will develop the required starting torque to drive the coupled load up to rated speed.

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