Application Guidance Notes: Technical Information from STAMFORD | AvK

AGN 193 – Application of Multiple Loads

INTRODUCTION

The question is often asked about how to consider the performance of a Generating Set when various loads are to be applied sequentially. The process involves a logical approach with certain key factors, which must be considered and here there is no substitute for experience.

MULTIPLE LOADS ADDED IN STEPS

The application of a load step on to an alternator's output terminals will kick into action the alternator's sub-transient reactance (X"d) and transient reactance (X'd). These reactances are combined and referred to as Xg. X"d and X'd are the two parameters that react to a sudden change to the level of applied load and together, they set the magnitude and gradient associated with the initial 80% of the total Transient Voltage Dip percentage. The final additional 20% of the total TVD% is at a different gradient, as this is managed as a function of the dynamics of the AVR's forced excitation, which is dependent upon the AVR's provided power source.

So in fact, it is only the impact kVA of the suddenly applied load that should be considered with reference to the Locked Rotor curves, but this is a very isolated / purist type of approach.

In the real world, considerations need to take into account the fact that the applied impact load may take both engine and alternator to the extremes of their control function ceilings; here, think in terms of AVR excitation ceiling and engine governor's black smoke fuelling limit.

If the applied peak load does exceed rated kVA, then the actual degree of overload being imposed on the Generating Set may well mean that the published fixed speed Locked Rotor curves for the alternator will need to be viewed with experience; to introduce a factor to compensate for a reduced running speed, resulting from the engines capability to accept the calculated peak total loading level. This is a situation that may not be supported by the engine manufacturer's provided data.

Furthermore, when considering motor starting, one of the most important aspects to be taken into account is related to the rate at which the motor will accelerate to rated speed, which controls the rate at which the motor's slip frequency is reduced, thereby, the level of inrush kVA. In turn the power factor will rise, resulting in a demand for real power from the engine as the electric motor begins to do its work. Unfortunately, such detailed information regarding the motor's performance is rarely provided.

With regard to the effect of a newly applied load to the Generating Set, some thought needs to be given to that initial instantaneous demand for Generating Set power. The engine is not able to provide an instantaneous response with a stepped increase in power. However, through this initial time period, the spinning mass associated with the coupled engine and alternator will have a combined inertia (H) able to provide a level of kinetic energy. This will assist in providing a continued level of speed, maintaining ride-through until the control function response results in increased fuel. In turn, enabling the engine's recovery to nominal speed and stability at nominal speed.

In order to appreciate the peak and steady state loading levels at each stage and step of the various load applications, an engineered approach towards gaining a simple understanding is to create a Load Diagram. The Load Diagram will depict the cumulative picture of kVA, kWe and related demand for kWm, as each step is applied.

There follows an example, with a technical explanation, of sequential load steps and the creation of a Load Diagram.

Considerations of transient conditions for Prime Power and Emergency Standby Power variable loads.

The Generating Set industry standard, ISO 8528-1, Paras. 13.3, focuses on the variable load against time periods that would affect the power rating. It does not specifically identify transient effects when those load steps are applied or removed. The normal situation would be that, to achieve significant load steps, motors would be started and it could well be that the maximum power requirement during motor starting dictates the engine power requirements and alternator size.

The following example serves to illustrate the point:

- A Generating Set is required to operate under normal reference conditions to provide a nominal: 660 kVA, 528 kWe, 0.8 power factor, 415/240 volts, 3 phase, 4-wire, 50Hz at 1500 rpm.

- The total load is identified as: a base running load of 344 kWe, which is 430 kVA at 0.8 power factor, together with 2 x 75 kWm motors, which are to be sequentially started by

Direct-on-Line (DoL) method and then some 35 kWe, which is 43.7 kVA at 0.8 power factor, of non-essential load.

- During the DoL starting of the 75kWm motors, the locked rotor condition will demand some 6.5 times rated kVA at a power factor of 0.15. Once running at rated speed they have a typical full load operating efficiency of 92% and 0.88 pf.

- During the sequential starting of each 75kWm motor the resulting Transient Voltage Dip (TVD) must not exceed 20%.

- The above described loads are to be applied in the following sequence:

  - Step 1 Base running load applied.
  - Step 2 First 75kWm DoL motor started.
  - Step 3 Second 75kWm DoL motor started.
  - Step 4 The Non-essential load applied.

From the provided information, it is possible to determine the 75kWm motor's likely transient loadings imposed on the Generating Set by considering the available motor information:

- The running kVA: the motors shaft power (advised as kWm) is divided by the motor's full load efficiency and divided by the full load power factor.
  = 75 divided by 0.92, divided by 0.88 **= 93kVA.**

- The start kVA: the running kVA x 6.5.
  = 92.6 x 6.5 **= 602 kVA.**

- The start kWe: the start kVA x the start power factor.
  = 602 x 0.15 **= 90 kWe.**

With the motor calculations completed, all load steps now identified and the loading sequence understood, the creation of a simple Excel spread sheet shows the cumulative step by step situation. The example spread sheet is on the next page - Table A – Introduction of Multiple Loads.

Comments on Table A:

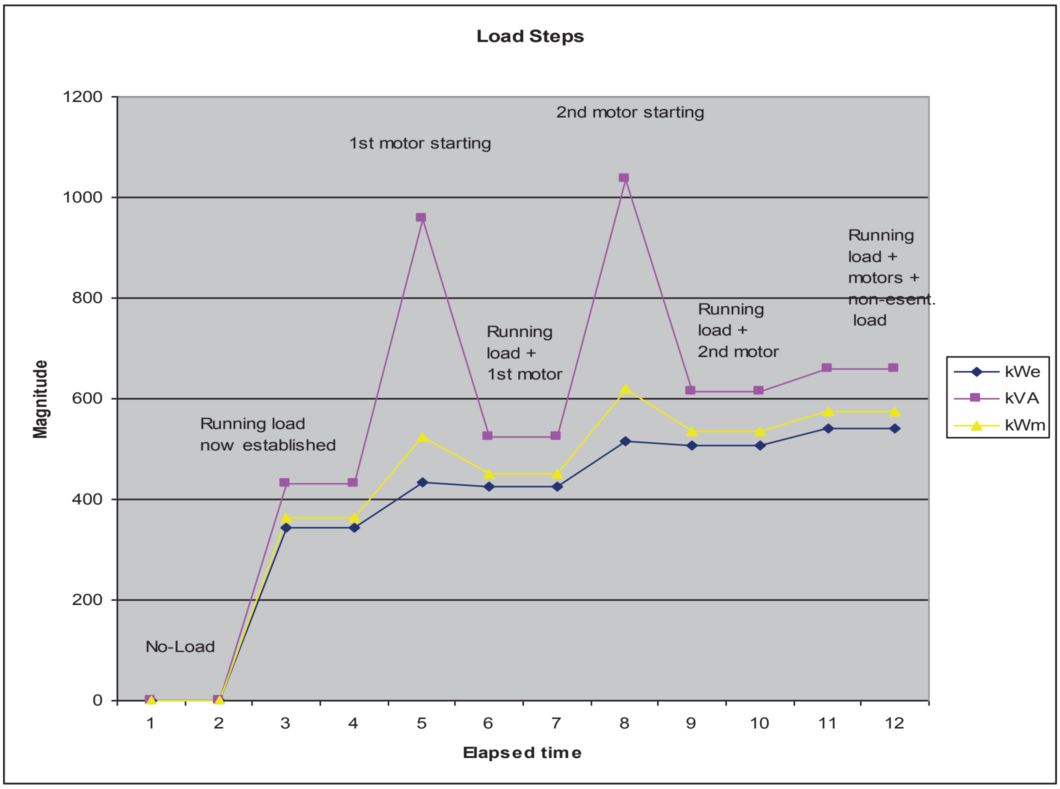
** The cumulative transient kVA is not a direct sum of the steady state load kVA plus the starting motor's kVA, rather a calculation that takes into account a mathematical summation of the two individual loads summed together kWe and kVAr, and then cumulatively identified by:

- kVA = $\sqrt{(kWe^2 + kVAr^2)}$.

Load Sequence		motor power		motor effciency		motor p.f.		Running Load		Transient Load as each motor is started		**Total Load steady state levels**		Peak Total Transient load as each motor starts	
	kWm	pu	pu	kWe	kVA	kWe	kVA	kVAr	pf	kWe	kVA	pf	kVAr	kWe	kVA
Running load (base load)				344	430					344	430	0.80	258		
1st motor applied	75	0.92	0.88			90	602	595	0.15					434	957**
1st motor running + base				82	93					426	523	0.81	303		
2nd motor applied	75	0.92	0.88			90	602	595	0.15					516	1036**
Both motors running + base				82	93					507	615	0.82	349		
Motors + base + non-essential load				35	44					542	659	0.82	375		

Table A – Introduction of Multiple Loads

Using Table A, in its Excel spread sheet format, a graph can be created which diagrammatically illustrates the transient and steady state operating conditions as each load is applied and becomes steady state. A Load Diagram based on the above data follows:



Graph A – Introduction of Multiple Loads

The load sequence shown in Table A and Graph A both illustrate the most challenging period occurs as each 75kW motor is applied.

Using the advised alternator efficiency level of 94.5% under steady state load conditions and an assumed value of 83% during each motor start condition (accepting this is a simplified approach), guidance for the required levels of engine power (kWm) can be established. This now enables Graph A to illustrate the three main parameters for considering required levels of Generating Set performance under transient and steady state load conditions.

Once the entire load has been applied and has stabilised to steady state conditions, it is clear the Generating Set must be able to support a total load of 660kVA, 542kWe, 0.82pf. This becomes a key value towards initial considerations of the continuous rating required of the Generating Set.

When selecting the engine and alternator, the process must take into account the specified requirement that during the motor starting events, the TVD shall not exceed 20%.

From Table A (or Graph A) the selection of the alternator must be guided by the loading levels, which will prevail as each motor is started with an inrush of some 602kVA. When each motor is started the alternator is subjected to a momentary overload, which during the starting of the second motor results in a peak demand from the Generating Set of some 1036kVA. This represents a 60% overload when compared to the identified steady state running load of 660kVA.

The implication of such a momentary gross overload needs careful consideration with regard to the selection of the engine and alternator, along with identification of their combined inertial mass.

From Table A the selection of the engine, in terms of peak and continuous levels of kWm, can be established.

For the steady state condition, where the entire required load has been applied, the following calculations will provide guidance for the required level of engine power:

- To establish the alternator efficiency, the operating power factor (pf) at full continuous rated load needs to be calculated: 659kV, 542kWe, from which the steady state pf can be calculated; 542/659 = 0.82 pf.

- To calculate the required engine power kWm for this steady state continuous condition: Divide the electrical kWe by the alternators efficiency, which has been given as 94.5% for the 542kWe, at 0.82 pf. This identifies the required level of steady state continuous engine power as: 542kWe / (94.5/100) = 574kWm.

- To calculate the required peak level of engine power the following values are considered: 1124.6kVA, 515.5kWe, from which the peak condition pf = 515.5 / 1124.6 = 0.46pf.

- To calculate the required engine power for this peak condition: Divide the peak electrical kWe by the alternators efficiency for this overload at low pf condition, identified as 83%. Peak level of engine power required = 515.5kWe / (83/100) = 621kWm.

Due consideration needs to be given to the chosen engines Technical Data Sheet to ensure it is suitably rated for operating at the continuous output power level of 574kWm and have the capability to provide the transiently required peak power level of 621kWm.

This aspect of considering the predicted peak power level against the engines published Technical Data Sheet becomes contentious, because the time duration of this peak kWm is unknown.

Reference to a Technical Data Sheet for an existing design of Generating Set is the next logical step, where the continuous rating and peak load ratings will be published, along with load acceptance characteristics, described in terms of capability, with resulting levels of predicted transient voltage dip and frequency dip in percentage terms. At this stage the specified need for no more than a 20% transient voltage dip as each motor is started has to be kept in mind.

If the specification requirements cannot be met with an existing design of Generating Set, then the way forward is a pragmatic approach to identify an individual engine and an individual alternator, which can be incorporated into a bespoke Generating Set.

The Technical Data Sheet for the alternator will include a graph to advise of load acceptance capability, often referred to as the ‘Locked Rotor Curves’, which illustrate the resulting TVD% as a step-load, with low lagging power factor, is applied to the alternator.

This example considers an application where the penultimate applied load applied is a DoL 75kWm motor. In terms of both gross overload and TVD%, the allowable disturbance to the electrical system will be decided against the need to ensure both the voltage and frequency variations will not promote de-stabilisation of the already connected electrical loads.

It must be remembered that the alternator manufacturers provided Load Acceptance information is based on the industry standard IEC60034 conditions, where tests are conducted under **constant** rated speed conditions. However, once this alternator is engine driven, constant speed is unlikely to be maintained and so, with regard to the identified motor start conditions, any required load acceptance considerations should be based on test data for the proposed design of Generating Set.

Performance data for the proposed engine must be considered with regard to load acceptance capability. The engine data provides details of typical transient levels of speed dip behaviour under applied load step conditions, indicating the magnitude and duration of a speed dip resulting from different stepped levels of applied load from varying levels of base load conditions.

The above Table A and Graph A contain such information.

Note: Misunderstandings regarding the performance capability of a Generating Set can arise if performance expectations are based on load step acceptance performance datasheets specific to just the engine and just the alternator. As in isolation, such data does not offer guidance on how the engine and alternator's control functions will interact once the pair are coupled as a Generating Set.

Now, the beneficial effect of the coupled pair's 'stored' kinetic energy can be beneficial in terms of assisting to maintain running speed for moments after the load step has been applied and in the case of motor starting, provide a beneficial 'energy kick' to assist the motor with its need to develop breakaway torque and begin accelerating from rest towards rated speed. During this dynamic period the control functions of both the engine and alternator independently respond by appropriately controlling fuelling and excitation as they strive to ensure rated speed and voltage are restored, maintained and stabilised.

stamford-avk@cummins.com

www.stamford-avk.com

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