Paper No. 40

Electrical/Electronic Components

Generator Selection For Movable Bridges

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TENTH BIENNIAL SYMPOSIUM

OCTOBER 25 - 28, 2004
The Omni Orlando Resort at ChampionsGate

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Introduction

Electrical power has become an essential part of our daily lives and when it is interrupted or not available, the ability to do our jobs or to be able to function in a normal manner becomes an imposition to our daily routine. When our daily functions are not performed in a timely and efficient way, then it becomes too costly to permit these times of non production to continue more than a few minutes in duration. This has also become true for the operation of movable bridges. When a mariner it traveling one of our waterways that contain a movable bridge and the bridge needs to be moved in order for the journey to continue, then the bridge needs to be moved at that time, not later when the electrical service is restored. The same would exist for the motoring public or for a railroad shipping the nation's goods across the rail network from manufacturer to consumer. The mariner wants the bridge raised so he can continue his journey and the railroad or motoring public wants the bridge lowered so they can get to their final destination in a timely manner.

Why Do We Need A Generator?

The United States Coast Guard mandates that a movable bridge shall be opened upon request within a reasonable amount of time and without undue delay to the mariner. The result is a need to provide auxiliary power to the bridge through the use of a second electrical utility power source, an alternate method to operate the bridge such as hand cranks or standby generators. The availability of a second electrical utility power source to movable bridge locations is a rare situation. The second utility source needs to be from a sub station that is different from the primary source sub station in order to provide a reliable back up power source that would be available during power outages other that wide spread power failures similar to a complete utility shutdown over a wide area. Manual operation using hand cranks are no longer a practical method of opening or lowering a bridge due to the time required and the safety concerns of the personnel performing the manual operation. This leaves the option of a standby generator set to provide the back up electrical power as the best method.

AASHTO sections 2.10.23 and 2.10.24 describe the requirements for the engine generator sets and standby power systems. Similarly, sections 6.7.5.12 and 6.7.5.13 in AREMA discuss the requirements for railroad bridges. AASHTO requires that power for continuous services, such as lights, navigation signals and bridge operating equipment are to be in operation or available for operation at all times during a power failure of the primary power source.

What loads should be considered when sizing a generator set for a movable bridge? The basic loads that are usually constant and always present on any movable bridge are lighting, heating and air conditioning. In addition, the basic power needed to supply the control system and drive system in an idol state of operation will also need to be taken into account. These loads will be present on the generator when the generator is placed into service in the event of a loss of the primary utility source. In addition to the basic loads, the operating loads of the bridge drive equipment are included in the total loads for the bridge. These loads include the drive motors and drive controllers, the motor brakes and the machinery brakes. The size of these loads from the drive motors will vary depending on the size of the motor, the power requirements of the drive controllers and external variables such as wind, rain and ice. The loads from the brakes will remain basically constant and will not vary depending on contributions from the external factors. Another factor that has an effect on the size of the generator is the starting configuration of the drive motors and brakes. If the bridge is a double leaf bascule bridge with span locks located at the leaf tips, then the option of staggering the starting of each leaf could reduce the size of the generator required to operate the bridge. By staggering the two leafs, the starting loads for the two leafs can be equally distributed and thus reduce the starting KVA to the generator set.

The type of load will also have an effect on the size of the generator. Starting a squirrel cage AC motor using an across the line starter contactor will result in a higher starting KVA than starting a single DC motor or two DC motors using state of the art drive controllers. Figure 1 details the load comparisons of starting a single 20 HP motor, a single 30 HP DC motor using a solid state drive controller and starting two 30 HP DC motors using the drive controllers.

LOAD COMPARISON STUDY
CANADIAN PACIFIC RAILROAD BRIDGE 282.82
LA CROSSE WI

HEAT LOAD	LIGHT LOAD	MOTOR LOAD	VOLT. DIP	START KVA	RUN KVA	GEN SIZE
18.72 KW	2.0 KW	1 - 20 HP AC	12.62%	133.75 KVA	45.23 KVA	100 KW
18.72 KW	2.0 KW	1 - 30 HP DC	13.36%	71.9 KVA	54.69 KVA	60 KW
18.72 KW	2.0 KW	2 - 30 HP DC	11.07%	115.94 KVA	84.16 KVA	100 KW

NOTES:

1. The AC motor was a standard squirrel cage motor with across-the-line starting.
2. The DC motor was controlled from a solid state variable speed drive controller and a current limit set at 150% of the full load output.
3. Load studies did not consider harmonics in size the generator.
4. Generator selection was based on a 3 phase, 277/480 volt, wye, propane fueled unit.
5. Generator sizing is based on QuickSize v8.2 provided by Kohler Power Systems.

Figure 1

The results of this study show that the 20 horsepower AC motor placed the highest starting KVA and highest percentage of voltage drop on the generator. Therefore the AC motor was the governing factor in the sizing of the generator for this project. As stated in Note 3, no harmonic distortion was taking into consideration for this study and no special requirements were specified for the generator set to account for the harmonics that the DC drive controllers would place on the generator during operation. In order to prevent the possibility of operational problems caused from harmonic distortion, the control system was interlocked to prevent operation of the main drive motors whenever the generator was operating.

All generator sizing programs have the capability to apply drive motors that use solid state drive controllers and allow the user to set the current limit capacity up to 300%.

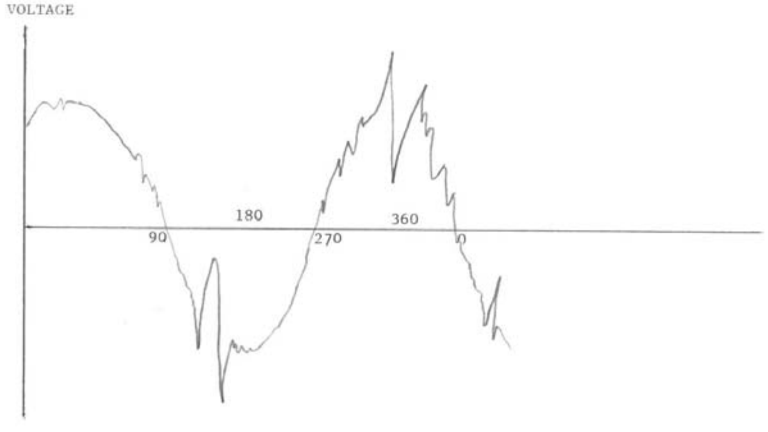
Common Pitfalls in Generator Selection

Harmonic Distortions

Harmonics are a result of nonlinear loads created by the voltage and current manipulations within solid state drive controllers for AC and DC motors. The results are can cause heating effects within the generator and premature failure of the generator.

What is a nonlinear load? Before discussing a linear load, we should first define what a linear load is. A linear load is a load device that contains only resistance, inductance and/or capacitance. The devise will not alter the sinusoidal voltage and current waveforms other than reducing amplitude and shifting the respective phase angle. Devices such as variable frequency drives, UPS systems, high density lighting controls, or any device which contains Silicon Controlled Rectifiers (SCR's), are considered nonlinear. The drive controllers of today's technology contain SCR's, commuted circuits, transformers, diodes and high speed switching components. These are nonlinear because they do alter the sinusoidal waveform and produce frequencies other than the applied source frequency.

Nonlinear devices which alter a nearly sinusoidal power waveform impose harmonics on the power system. The utility line can absorb these harmonics onto the utility grid with little problem. A device such as a SCR distorts and chops up a clean sinusoidal waveform such as those produced by the utility or generator set power sources. The SCR rapidly switches on and off allowing the current to pass only at selected times during the available 60 hertz sine wave. The results of this rapid switching are distorted voltage and current waveforms similar to those in Figure 2.



Harmonic Distortion
Figure 2

Variable speed drive controllers include Variable Frequency Drives (VFD), Flux Vector Drive (FVD), Thyristor Drives and DC Drives. VFD's and FVD's are utilized to control the speed of AC induction motors. Thyristor drives are utilized to control the speed of AC wound rotor motors and of course, DC drives are utilized to control the speed of DC motors. Each of these drive controllers use SCR's to manipulate the voltage waveform to control the speed of the motor. How this is accomplish within each of these types of drive controllers will not be discussed in this paper but each type of drive controller will create harmonic distortion on the power system.

To help deal with the harmonic effect of these type of nonlinear loads. IEEE 519 provided guidelines as to acceptable voltage distortion levels. For general loads, the acceptable level of distortion is 5%. For dedicated loads, the acceptable level is 10%. Since a generator is only in service for limited time on movable bridge applications, most generator systems can withstand more than 10% distortion, however the standard industry practice is to limit the total harmonic voltage distortion level to less than 15%. Above this level, the generator system could experience problems.

Nonlinear loads are know to cause heating in distribution and generating systems. The heating is a direct result of the increased levels of harmonic content. Conductors and protective devices in distribution system are affected. Nuisance tripping of thermal circuit breakers and fire can result. Generator windings can overheat causing reduced generator life or winding insulation failure.

To minimize this distortion, the generator's impedance needs to be held within acceptable limits. The base KVA of the alternator selected should be adequate to limit the subtransient reactance to 6-8%. Generally, if the generator is sized to minimize harmonic distortion, alternator overheating due to harmonic currents is no longer an issue.

Other solutions for controlling harmonic distortion include active or passive filtering to remove harmonic currents. Also, additional loads that can be added to the system prior to starting the nonlinear load will help minimize distortion.

A general rule of thumb is that SCR loads on a generator should be less than 50% of the generator capacity to limit total harmonic voltage distortion to 15%. In addition, when using a generator for SCR applications, size the generator for the full nameplate rating of the drive and not the motor.

Whenever alternate methods of bridge operation other than SCR drives can be utilized when a generator is being used, the problem of harmonic distortion is virtually eliminated. An example of this would be the application of an AC squirrel cage motor using an across the line motor starter as the back up drive system.

In summary, dealing with nonlinear loading of generators is not a simple task. It requires some understanding of the nature of nonlinear loads and awareness of some of the problems that may occur.

Motor Starting

Motor loads have a significant effect on the size of the generator set due to the high currents required to start the motor. The method of using full voltage across the line motor starting is the most common because of the simplicity and low cost. Using the across the line method places the full line voltage to the motor windings and the instantaneous inrush of current occurs when the motor is energized. This is also known as locked rotor current or starting current.

The magnitude of the starting KVA can be calculated from the motor nameplate data. Most motors are identified with a NEMA starting code letter that describes their individual starting characteristics and is shown in Figure 3.

Code Letter	skva/HP
D	4.0 – 4.5
E	4.5 – 5.0
F	5.0 – 5.6
G	5.6 – 6.3
H	6.3 – 7.1

NEMA Starting Codes
Figure 3

It should be noted that if IEC rated motors or high efficiency motors are used, these motors tend to have higher starting current requirements that do standard NEMA motors.

The alternator must have sufficient motor starting KVA capacity to limit voltage dips to acceptable levels. In rush current to the motor causes a rapid dip in generator output voltage. As motor size increases, the voltage dip that is seen at the generator increases. The majority of the industry has established a maximum voltage dip of 35% as being the acceptable alternator limit. However, some sensitive equipment may only be able to handle as little as a 15% voltage dip. The voltage dip occurs within a few sine wave cycles upon connecting the motor to the generator output. This voltage dip can be minimized by increasing the size of the alternator because larger alternators have lower impedances. When the alternator senses the instantaneous voltage dip, the alternator excitation system responds by increasing excitation to recover to rated voltage. The electric motor load will accelerate towards running speed provided it produces enough torque to overcome its shaft connected load. For induction motors, torque is directly proportional to the square of the applied voltage. Motor acceleration is a function of the difference between motor torque and the torque requirements of the load. The alternator needs to recover to rated voltage as quickly as possible to avoid excessive acceleration times or motor stall. Generator set components are designed to achieve the shortest possible response time while maintaining voltage stability and avoiding engine overload.

What is the best type of generator set?

The fuel source of the generator can be a factor to the application of the generator to the project. The three types available are diesel, natural gas, propane (LP) and gasoline. Each has their own advantages and disadvantages depending on the client, type of loads and local conditions.

Gasoline fueled generator sets are not commonly used due to the fuel handling and fuel storage problems that exist. Gasoline can present a significant fire hazard problem to store large amounts on site. In addition, gasoline has a limited storage shelf life and can go bad resulting in an increased amount of maintenance cost if the deteriorated fuel was used to operate the generator set unless additives are added to the fuel to prevent deterioration and to help stabilize the fuel. Finally, the typical gasoline fueled generator is less than 50KW for most of the manufacturers.

Diesel fueled generator sets are the most common and are usually the least expensive when comparing the basic generator set to the cost of a natural gas or LP fuel generator set above 100KW. A wide variety of generator sets are available beyond 1000KW. When using a diesel generator set as the back up source of alternate power for both the basic constant loads and the power requirement need to operate the bridge can result in the generator being to lightly loaded for the majority of the operating time. When a diesel generator set operates with a light load for an extended period of time, the cylinders do not burn the fuel efficiently and the cylinders can become fouled with carbon. This condition is not found on natural gas generator sets because natural gas is a cleaner burning fuel than that of diesel fuel. The only effective method to eliminate this condition would be to have the generator set operate with a minimum load of 50% of the rated output at all time. AASHTO supports this method of operation by as stated in Section 2.10.23 where it states "If one unit supplies both power for span operation and for auxiliary services, provisions shall be made to maintain 60% of the unit's nameplate loading at all times to prevent carbon accumulation." In order to satisfy this requirement if the loads from the auxiliary services or the basic constant loads are not adequate to maintain the minimum recommend load, then the use of a load bank on the output of the generator set is required. This option then adds a cost to the base price of the generator resulting in costs that are comparable to those found for natural gas generator sets.

Diesel fuel generator sets require large external fuel storage tanks to reduce the frequency of refueling during extended periods of operation. This is becoming an increasing environmental problem on movable bridges with the proximity of the structure being near or over waterways. Double tanks and fuel containment in the event of a fuel spill are required under current EPA regulations.

Natural gas generator sets are becoming available in a greater variety and also in larger units that what is been available in previous years. The natural gas generator provides a cleaner burning fuel source that with diesel or gasoline. As a result of this, the unit does have the carbon build up problem experience with diesel fueled generator set and therefore does not require the external load bank to maintain the 60% load required by AASHTO. With a natural gas fueled generator set, the fuel source is provided by a local natural gas supplier and is therefore virtually unlimited. Natural gas does not have the fuel handling problems that exist with diesel and do not have the environmental problems associated with diesel fuel. As a result of the cleaner operation with natural gas, the maintenance costs are reduced.

The initial cost of a natural gas generator is higher when compared with a diesel generator, but with lower maintenance costs and the elimination of the fuel handling problems and environmental problems result in a lower net cost when averaged over a 3 to 5 period depending on the total amount of usage during that time period.

The advantages and disadvantages of using LP fueled generator sets are similar to those of the natural gas generator set with the exception of the requirement of fuel handling since a storage tank would need to be located on site and refueled periodically.

Summary

The selection of a generator set can result in operation problems to the client that may not be arise during the initial start up process. A generator must be properly sized to handle the operational loads that a movable bridge will demand under all operating conditions, each day of the year. The operating conditions are the highest when a bridge is required to operate during the most severe weather conditions which are set forth in AASHTO Section 2.5.3 under the conditions outlined for the Case C loads of wind and ice loads. If a generator is being used to provide power where solid state drive controllers are the method used to operate a bridge in the event of a power outage, the generator needs to be large enough to both start the drive under a high starting load, but to be able to handle the harmonics that are at an increased level during the acceleration and operation of a solid state drive controller. To eliminate the problem of harmonics, the use of a smaller and slower AC induction motors with an across the line motor starter would not only eliminate problem of harmonics on movable bridge operations, it could at times, reduce the size of the generator depending of the final size of the main drive motors and the auxiliary drive motors.

The selection of the type of fuel source is something that requires serious consideration. The factors that contribute to this selection are the client's desires, the local conditions with respect to the location of the generator, environmental conditions and the available fuel sources. Natural gas generator sets may present the best type of unit over a diesel generator set if the local conditions would permit this option.

Although the cost of the generator is a small percentage of the total costs of a complete electrical distribution and control system, the selection of an improperly selected and designed generator set could result in conditions where the client is expecting to be able to operate the bridge and then have the generator fail to function properly when is it the most critical to the client. The result could be the owner receiving fines from the United States Coast Guard for failure to operate when required to do so as well as bad public relations from the motoring public if the bridge gets stuck in the raised or partially raised position during a power outage.

References:

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