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AN ANALYSIS ROUTINE FOR SIZING AND SELECTION OF GENERATING SETS FOR INDUSTRIAL APPLICATIONS

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ABSTRACT

The chronic instability of the Nigerian power system has forced many manufacturing, service and construction companies to acquire electric power generating sets. These sets are for stand-by, peak-lopping or total power generation services. A preliminary survey carried out in July 2003 involving thirty service users in Onitsha and Nnewi industrial areas revealed a complete disregard for prime-mover characteristics in the sizing and selection of these sets. This paper presents practical guidelines for practicing engineers for the sizing and selection of generating sets for industrial buildings. The guidelines are presented in form of an analysis discussing all the crucial factors required for proper sizing and selection. The paper concludes by emphasizing the importance of alternator and prime-mover characteristics for proper continuous load rating

Keywords: *alternators, prime-mover, sizing/ selection, guidelines.*

INTRODUCTION

Power generation through electric generating sets is an expensive venture in terms of capital and running costs. The duty to select the required unit falls between the client and the manufacturer or supplier. Primarily, the manufacturer bears the burden of providing suitable sets, but considering the capital investment involved, it is economically expedient for the users engineer to play a part in the selection process. This ensures that units appropriate to particular load conditions are selected. In the preliminary survey, the following 10 factors were presented to the users' engineers to pick the ones they usually consider, in the sizing and selection of their generating sets:

(i) Load-matching capacity of the prime-mover(engine).
(ii) Engine noise level.
(iii) Engine reliability
(iv) Load pick-up capacity of engine
(v) Power to weight/Power to volume ratio of the engine
(vi) Power restoration speed of the engine
(vii) Speed regulation of the engine
(viii) Load capacity of the alternator
(ix) Permissible frequency and volume excursions of the alternator

Factors (i) to (vii) are prime-mover characteristics while (viii) to (x) are alternator characteristics. For this investigation, generating sets imply units comprising turbo-charged gas/diesel engines or turbines coupled to alternators of not less than 250kva capacity. In other to avoid guesswork and its attendant consequences the above mentioned factors must be considered for proper sizing and selection.

ANALYSIS OF THE FACTORS FOR PROPER SIZING AND SELECTION OF GENERATING SETS

For all situations, the use of stand-by ratings must be avoided. The crucial points to be evaluated are:

1. Engine (prime-mover) capacity (KWm)

This is an often neglected factor in the sizing and selection of electric power generators to the detriment of the user. The load acceptance limit of the prime-mover coupled to the alternator is of utmost importance. Infact, this is more important than the KVA capacity of the alternator in order to ensure an effective continuous load rating (Shearer, 1981).

In selecting a suitable engine, the following characteristics must be evaluated:

a. **Noise Level:** The noise level of the engine is influenced by the over-all design of the engine. For low noise level, water cooled engines are preferred to the air-cooled types due to the following reasons:

i. The rigidity of their construction and the presence of water itself have a noise absorbing effect

ii. Cooling fins of air-cooled engines act as soundboards. Also air-ducting and paneling around air-cooled engines are sources of noise producing vibrations.

b. **Reliability:** Generally, water-cooled engines are more durable and reliable than the air-cooled types. They are also cheaper to maintain. A typical 4-cylinder air-cooled engine will cost over twice as much in routine service operations as an equivalent 4-cylinder water cooled engine (Petbow Information Service, 1982).

c. **Load Matching Capacity:** The engine capacity must correspond to the anticipated load under local conditions. For example, at high altitudes engine power is decreased because of the lower atmospheric pressure. Thus engines required for operations at locations high above sea level must have higher power rating than those located at lower altitudes. Temperature also, has an effect on engine power output. A 2% derating in engine power output is usually given for every 5.5°C increase in inlet temperature. This is very crucial for engines working in the tropics and also for indoor installations.

d. **Load Pick-up Capacity:** The ability of the engine to pick-up load from cold is a crucial factor to be considered for good performance of any generating set. Barber (1982) holds that engines with mechanical speed-governing systems have better pick-up capacity than those with electronic governing systems. Also, one outstanding advantage of gas turbines is their ability to produce full power in 2 minutes from cold(Cohen et al, 1996). Due to the instability of the Nigerian power system, this capability should be treated with caution to avoid thermal shock to the engine. This is because gas turbines are very sensitive to sudden upward load variations while operating at peak load. Hart(1993) holds that these power variations may result in the stalling of the compressors leading to a temporary shut down.

e. **Power to Weight and Power to Volume Ratios:** Installation on make-shift structures and cramped locations require engines with high power to weight and power to volume ratios. This ensures that efficiency is not sacrificed to lack of space. For improved efficiency, turbo-charged engines are recommended for higher power to weight ratio. Turbo-charging means more (output) power and more power means more heat generated by burning fuel. Thus valves, pistons and fuel injectors are subjected to greater thermal loading. This is usually offset at the design stage by improved coolant flow and lubrication. Also, bearings and crankshafts are designed to withstand the additional stresses by the higher mechanical loading. The serious implication of this is that on no condition should a turbo-charger be added to an engine that was not designed for it. The performance and life-span of the engine is drastically reduced if this done.

f. **Power Restoration Speed:** This engine characteristic greatly influences the capital cost. If an interruption of some duration (up to 5 minutes) can be tolerated, the maximum possible restoration time should be used in selecting an engine as this allows possible savings in capital cost. For a break of 10 seconds to full load, reciprocating engines and single shaft gas turbines are recommended (Barber, 1982). For a break of 30 seconds to 60 seconds to full load, two shaft gas turbines are most suitable.

g. **Speed regulation:** the governor could be mechanical, hydraulic or electronic. For fine governing a 4.5% droop from no load to full load is normally allowed(BS 649). In a power system where only a small variation in frequency is tolerable, close governing down to about 1.5% droop is allowed. For other conditions, close governing may result to instability(Bell, 1971).

Refs(8,9,10) provide ample general guides for these factors.

2. Supply and load situation: Since a generating set is intended to simulate a mains supply, the correct sizing and selection should also be determined by the allowable temporary (transient) derivations during sudden load changes. The factors to be considered are:

a. **Permissible Frequency and Voltage Excursions During start-up and while Running:** This involves the period before the response of the engine governor and the automatic voltage regulator (AVR). In making this specification, the Engineer should bear in mind that frequency deviations of up to 8% (of nominal) recovering in 2 seconds and voltage deviations of up to 30% (of nominal) recovering in 0.5 seconds are not unusual. Fig.1 shows a normal generator voltage/frequency recovery characteristic. However, tight limits in frequency and voltage deviations may be off-set by extra engine or alternator capacity in excess of what is required for steady load demand. Generally, transient limits should be as wide as the load equipment tolerates. For a situation where a 15% frequency dip or more is not tolerable, an un-interruptible power supply (UPS) system must be interposed between the load and an automatic start generator. If a 15% or more frequency dip is acceptable and the unit is below 500KVA, then an inertia-start no-break generator is recommended (Shearer, 1981).

b. **Load Pattern:** The salient points to be considered here include; the type of load, initial load at start-up, subsequent load steps/timing and the transient loads during operation. Typical loads to be considered are:

i. **Heating and lighting:** For loads under this category, special attention is paid to all thyristor-controlled discharge tubes and similar systems. These systems are characterized by low power factor. They have very high starting characteristics and these figures in KVA are the loads seen by the generator. Thus for such systems, starting characteristics should normally be used for all load computations.

ii. **Lifts/Escalators:** For lifts and other similar systems, the starting characteristics of the electric drive motors should be used for load computations.

iii. **Motor Loads:** Most industrial installations include a number of electric motors (especially induction motors) usually of sufficiently large size to impose a considerable load on the generating set during starting. The highest starting peaks of these motors should be a pointer to the size of the generating unit. If a generating unit is selected to be just large enough to take the motors at full load, without regard for the starting requirements, the voltage dip caused by their starting may not be acceptable. Thus it is most essential to estimate the effect of the largest motor starting current on the generator.

iv. **Other Loads:** All other loads not included in (i), (ii) and (iii) are computed applying the appropriate diversity factor.

3. **Load Analysis:** Having determined the individual loads and their characteristics, load analysis is then required to determine the following generator ratings:

a. The continuous rating of the generating set under site conditions with all loads connected and running.

b. The generator rating required to meet the highest peak KW (kilowatt) demand during the application of a step-load plus other loads already being supplied.

c. The KVA (kilovolt-ampere) rating of the alternator required to handle the application of the largest KVA step load without exceeding the allowable voltage dip.

Generally, an engine overload rating of 110% of continuous rating (1.1 x Peak KW) is used to meet these conditions provided the maximum load step is within acceptable limits. To assess the effect of starting induction motors, it is important to know the starting factor; K. The product of k and the full load KVA approximates to the starting KVA. The starting factors for different types of motors and the method of starting is usually supplied by the manufacturer. The maximum KW during starting of squirrel-cage induction motors is approximated as 0.5 times the initial starting KVA. (Barber, 1983).

For wound rotor (ship-ring) motors, the maximum starting KW is found as the product of initial starting KVA and the assumed power factor at starting.

Table I is a specimen load analysis model. The individual load elements for each stage are listed in sequence of application with load description, method of starting and the starting factors. The calculations of initial KW starting conditions for applied load, peak KW and final KW for each stage can then be entered. Through these calculations, the cumulative effect of all the loads is manifested. From the load analysis table, the generating set can be sized in the following manner. Firstly, the continuous rating of the set must be equal to the final KW after the last stage of load application.

Secondly, the overload rating must at least be equal to the highest value of peak KW at any stage and the starting KW at any stage must be within the load acceptance limit of the engine. Usually, the alternator is sized so that the highest starting KVA of any stage results in a transient voltage dip within 30% of nominal.

RESULTS

(i) Out of the 30 users investigated, not one considered the prime-mover characteristics as sizing and selection factors.

(ii) Only 7 of then users considered the permissible frequency and voltage excursions of the alternator.

(iii)None of the users took the load pattern especially the starting characteristics of induction motors into consideration in the load analysis

(iv)All the users considered the load capacity of the alternator as the most crucial and necessary factor for sizing and selecting their sets.

CONCLUSION

The sizing and selection of generating sets for industrial applications require a sound technical appraisal of both the alternator and prime-mover characteristics. The two most important characteristics to be considered are the power handling capacities of the alternator (KW_E) and that of the engine (KW_M). The appraisal of these and their attendant factors coupled with proper analysis of the starting characteristics of all motor loads on the system leads to excellent installation and performance of selected sets.

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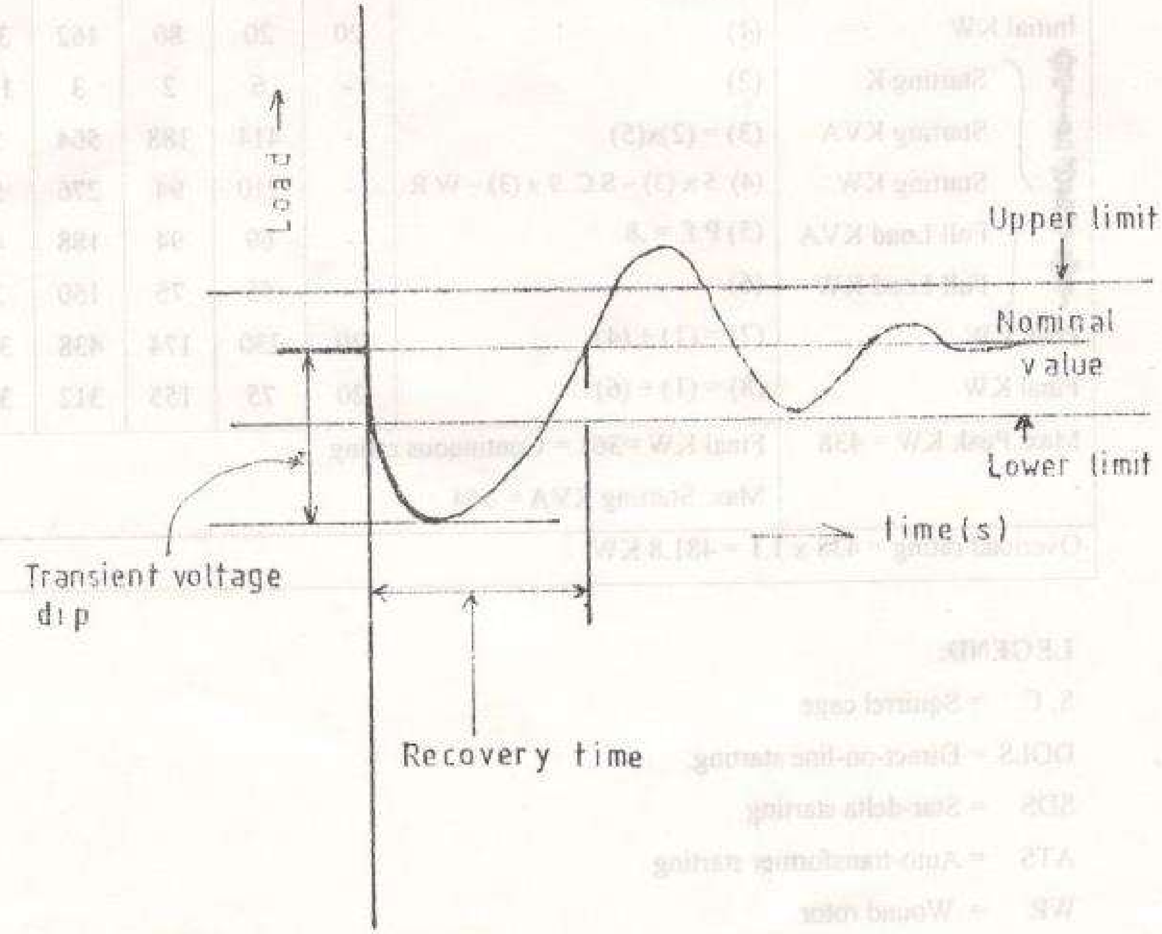

Fig 1: Generato voltage / frequency recorery characteristics.

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Table I: Specimen Load Analysis table

Load Element	Description					
A	20 KW Lighting and Heating.					
B	55 KW, S. C. motor – DOLS (K= 6)					
C	75 KW, S. C. motor – SDS (K=2)					
D	150 KW, S. C. motor – ATS (K=3)					
E	37 KW, W. T. motor – RS (K=1.25)					
	Line Ref.	A	B	C	D	E
Initial KW	(1)	20	20	80	162	324
[illegible] Starting K	(2)	-	6	2	3	1.25
Starting KVA	(3) = (2)x(5)	-	414	188	564	58
Starting KW	(4) .5 x (3) – S.C..9 x (3) – W.R	-	210	94	276	53
Full Load KVA	(5) P.f. = .8	-	69	94	188	46
Full Load KW	(6)	-	55	75	150	37
Peak KW	(7) = (1) + (4)	20	230	174	438	377
Final KW	(8) = (1) + (6)	20	75	155	312	361
Max. Peak KW = 438	Final KW =361 = Continuous rating Max. Starting KVA = 564					
Overload rating = 438 x 1.1 = 481.8 KW						

LEGEND:

S. C. = Squirrel cage

DOLS = Direct-on-line starting.

SDS = Star-delta starting

ATS = Auto-transformer starting

WR = Wound rotor

RS = Resistance starting