Step and Stage Size Considerations

Introduction

Northeast Power Systems, Inc. (NEPSI) is often asked to explain the difference between steps and stages relative to capacitor and harmonic filter bank switching. This technical note addresses the difference between these two terms and their impact on the cost and design of power factor correction equipment.

Background

Capacitor and harmonic filter banks are often designed utilizing vacuum switches or contactors (for clarity hereafter referred to as a switch) to switch capacitors "ON" and "OFF" in response to changing power system conditions, such as power factor, voltage, and var flow. It is generally desirable to energize large capacitor banks in incremental steps due to system characteristics, tariff structure, and prospective voltage rise. As the number of switched stages increase, so does the cost of the equipment. For this reason, large capacitor banks are broken into stages that follow an incremental format. In doing so, the amount of switching equipment (i.e. cost) can be significantly reduced while maintaining the same number of steps. It is best to illustrate this concept and its advantages by the example below.

Example

Consider a 12.47kV, 1,800 kVar switched capacitor bank. Table 1 below indicates some possible design options.

Table 1 – Various 1,800 kvar capacitor bank configurations

NEPSI Part #	# of Steps	# of Stages	Step Size (kvar)	Switching Sequence	Stage 1 kvar	Stage 2 kvar	Stage 3 kvar	Stage 4 kvar	List Price
ACB12.47/111	1	1	1,800	1	1,800	/	/	/	$37,268
ACB12.47/112	2	2	900	1:1	900	900	/	/	$44,400
ACB12.47/113	3	2	600	1:2	600	1,200	/	/	$44,321
ACB12.47/114	4	3	450	1:1:2	450	450	900	/	$55,586
ACB12.47/115	6	3	300	1:2:3	300	600	900	/	$55,586
ACB12.47/116	12	4	150	1:2:3:6	150	300	450	900	$67,146

Referring to Table 1, the following definitions apply for each column header:

Table 2 – Definition/Descriptions of Column Headers in Table 1	
NEPSI Part #	Part numbers for various NEPSI 12.47kV 1,800 kvar automatic metal enclosed capacitor banks. See the following link for a complete list. ***LINK HERE***
# of Steps	The number of possible switching outcomes. For example, for NEPSI Part# ACB12.47/113, there are (3) steps, or possible switching outcomes. These are 600 kVar (Stage 1 "ON", Stage 2 "OFF"), 1,200 kvar (Stage 1 "OFF", Stage 2 "ON"), and 1,800 kVar (Stage 1 "ON" and Stage 2 "ON").
# of Stages	A reference to the actual number of switches. Each stage contains (3) single phase group operated switches or one 3-phase switch. For NEPSI Part# ACB12.47/113, there are (2) stages, each containing (3) single phase group operated vacuum switches, for a total of (6) single phase vacuum switches.
Step Size (kvar)	The smallest amount of kvar that can be switched "ON" and "OFF". For NEPSI Part# ACB12.47/113, the step size is 600 kvar, and there are (3) steps. Each step will therefore increment by 600 kvar, up to 1,800 kvar (600, 1200, 1800).
Switching Sequence	Multiples of the step size, indicates the amount of kvar that will be switched with each stage. For NEPSI Part# ACB12.47/113, the switching sequence is 1:2. This indicates that there are (3) steps (add the two numbers together), and (2) stages. The second stage contains twice the amount of kvar as the first stage (1,200 kvar versus 600 kvar).
Stage # kvar	Amount of kvar installed in each stage. For NEPSI Part# ACB12.47/113, there are (2) stages, the first contains 600 kvar, the second contains 1,200 kVar.
List Price	NEPSI's budgetary list price. Contact NEPSI for your specific application.

Cost and Design Impact Considerations

As can be seen from Table 1, when specifying or comparing capacitor banks and harmonic filter banks, it is important to have an understanding of steps and stages. While all of the capacitor banks in Table 1 are 12.47kV and 1,800 kvar, their design and cost are significantly different. As the number of stages increases, cost will increase, primarily because more components, such as switches, protection relays, capacitors, fuses, and iron-core reactors (for harmonic filter banks), are required. The enclosure size also increases as the number of stages increases. The difference in list price between (2) stage and (3) stage capacitor banks in Table 1 is approximately $11,000. The cost difference for harmonic filters will be significantly more. For example, the difference in list price between a (2) stage and (3) stage 12.47kV 1,800 kvar harmonic filter bank is approximately $20,000.

For a given number of stages, the number of steps has much less of an impact on cost and design. Table 1 above indicates that NEPSI Part numbers ACB12.47/114 and ACB12.47/115 both have (3) stages, with ACB12.47/114 having (4) steps and ACB12.47/115 having (6) steps. The cost for both of these automatic banks is the same.

When switched capacitors are required, the minimum required number of stages must be specified, and if desired, the number of steps. If only the number of steps is specified, for example (3), one manufacturer may propose a (3) stage bank with 1:1:1 switching, the other may propose a less expensive (2) stage bank with 1:2 switching.

Stage Size Considerations

It is common practice for many engineers to specify medium voltage capacitor banks consisting of many steps/stages. This philosophy often comes from the low voltage industry, where steps sizes are seldom above 50 to 100 kvar. Low voltage banks are specified with these stage sizes for the following reasons:

- Contactors capable of switching stages with ratings greater than 100 kvar are not economical. For example, the cost of a contactor capable of switching 200 kvar is four times the cost for a contactor capable of switching 100 kvar. It is therefore more economical to switch two 100 kvar stages than one 200 kvar stage.

- Short Circuit KVA ratings are less, and therefore voltage rise and transient concerns become greater at this voltage level.

- Conductor ampacity for interconnecting components become unmanageable for stage ratings greater than 100 kvar.

At the medium voltage level, NEPSI recommends that designers consider larger steps and stages, keeping the following key points in perspective:

- Vacuum switches come in 200, 400, and 600 amp ratings. Smaller ratings are not available. A 200 amp vacuum switch can switch up to 3,300 kvar at 13.2kV. Therefore, to fully utilize the switch rating, which contributes a significant portion of the cost of the bank, larger stages should be considered. (Note: The economics of medium voltage is somewhat reversed from low voltage).

- Short Circuit KVA ratings at the medium voltage level are high in comparison to low voltage systems. Therefore, voltage rise associated with the application of capacitor banks is much less, and larger stage sizes can be applied.

- Most utilities do not charge for a leading power factor. Therefore, in applications where power factor penalties are of primary concern, it is more economical to utilize larger stages.

- Ampacities at the medium voltage level are low and most connections are made with copper bus bar. Therefore, interconnection of components at this voltage level is somewhat independent of stage size.

Conclusion

It is important that the terminology between step and stages be understood when specifying and comparing medium voltage capacitor bank quotes. Quotes that do not specifically state the number of stages and steps should be clarified. It should also be noted that some manufacturers may interchange the terms "steps" and "stages". When in doubt of what is being provided or specified, always request a three-line diagram.

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