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CUSTOM HARMONIC FILTER DESIGN FOR PORT CRANES

Shashank Mathur, Associate Application Engineer, TMEIC Corporation, Virginia, USA

With growing sophistication, complexity and demanding efficiency to operate the port terminals, there is tremendous emphasis on the technology used in electromechanical machinery design for cranes. Due to variation in the required power based on motion, weight, height, speed, torque and wind, the power requirements vary drastically and dynamically. As a result, magnitude and phase angle of the currents may change, affecting power factor, overshoot, harmonics and related phenomena. As the volume of machines goes up to meet the requirements of the business, degradation of power quality becomes a considerable concern for the grid operators. In addition, the harmonic levels also affect the smooth operation of drives, motors and other electrical equipment as they face thermal challenges due to increased line currents [1], leading to maintenance, reliability and safety issues with increased costs. This paper presents a case study to highlight the advantages of custom harmonic filter design in meeting specific criteria.

I. HARMONICS

A. ACTIVE FRONT END

With the growing popularity of variable frequency drives (VFDs), there is a concern over harmonics injected into the utility grid. Active front end (AFE) is an IGBT-based controlled rectifier [2].

A lower switching frequency to switch the IGBTs would result in higher switching ripple, and thus can introduce harmonics affecting the performance of other electrical components [5]. If the switching frequency is increased to minimize the above issues, some other issues like cooling, packaging, switching losses and increased cost arises.

B. IEEE-519 GUIDELINES

The IEEE-519 standard provides guidelines for limiting harmonic injection to maintain the quality of voltage at the point of common coupling. It requires that each user connected at the PCC meet the limits of THD and TDD. The limit for voltage and current harmonics , definitions of PCC, ISC, IL and TDD are referred directly from IEEE-519 [3] [4]:

Harmonic filters are used to limit harmonics introduced by nonlinear loads from being injected into the grid. They are used to compensate for harmonics distortion and to improve power quality. They also limit line current and improve power factor to control transformer kVA and neutral upsizing. Efficient design of the filter would ensure harmonic limits specified in the IEEE-519 are met and THD is minimized.

II. CASE STUDY: PORT CRANE HARMONIC FILTER

A. HARMONIC ANALYSIS OF 11KV SYSTEM

This case study is based on the data obtained from port authorities and analysis performed to estimate the harmonic distortion due to operation of multiple Automatic Stacking Crane (ASC) and Quay Crane (QC) systems. The focus is to highlight the custom design approach ensuring compliance of both local and global utility guidelines and to analyze performance of the harmonic filter against worst-case scenarios. It is interesting to observe the difference in harmonic injection between two different cases of load connected to utility bus. This provides an opportunity to study the impact on harmonic injection as the port business expands with the increasing demand to operate more cranes, resulting in increased nodes connected to the PCC contributing to higher harmonic distortion. Comparison between local utility planning levels for harmonic distortion with other standards such as IEEE-519 at 11kV is also discussed, to highlight that local utilities may have more stringent limits than IEEE-519 in some cases.

B. LOCAL UTILITY REQUIREMENTS

The harmonic distortion varies with the loading condition. To establish the criteria to evaluate the performance, local utility has provided with harmonic limit requirements at the point of common coupling. The worst-case scenario is based on the following assumptions:

- One of the 11kV Local Utility Feeders is out. Evaluations are based on Utility-1 and Utility-3.
- 11kV Local Utility Feeder supplies all loads.
- Main substation bus ties are closed.
- Harmonic voltages are calculated at Main Substation.
- Harmonic currents are calculated for 11kV Local Utility Feeder .

Utility-1 feeder power flow one-line output results in 2.959 MVA generation (Fig. 1). Fig. 1 shows 2.959 MVA generation. Equation (1) gives average maximum demand current. Short-circuit current ISC from simulation is 7.401 kA. Table 1 and equation (2) can be used to calculate current distortion, found in the range of 20-50.

$$I_L = \frac{MVA}{\sqrt{3}\,V_1} = \frac{2.959 \text{ x } 10^6}{\sqrt{3} \text{ x } 11 \text{ x } 10^3} = 155.3 \text{ A} \quad (1)$$

$$\frac{I_{SC}}{I_L} = \frac{7.401 \text{ x } 10^3}{155.3} = 47.65 \quad (2)$$

It is observed that in this case, the local utility has lower- limit requirements on both voltage and current harmonic injection to the grid. Table 3 shows comparative results

ISC/IL	3 ≤ H<11	11≤ H<17	17≤ h<23	23≤ h< 35	35≤H≤50	TDD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20-50	7.0	3.5	2.5	1.0	0.5	8.0
50-100	10.0	4.5	4.0	1.5	0.7	12.0
100-1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Table 1. Current Distortion Limits (in % of IL) for General Distribution Systems (120-69,000 V)

PCC Voltage	Individual Harmonic (%)	THDV (%)
V ≤ 1 kV	5.0	8.0
1 kV < V ≤ 69 kV	3.0	5.0
69 kV < V ≤ 161 kV	1.5	2.5
161 kV < V	1.0	1.5

Table 2. Voltage Distortion Limits (in % of V1)

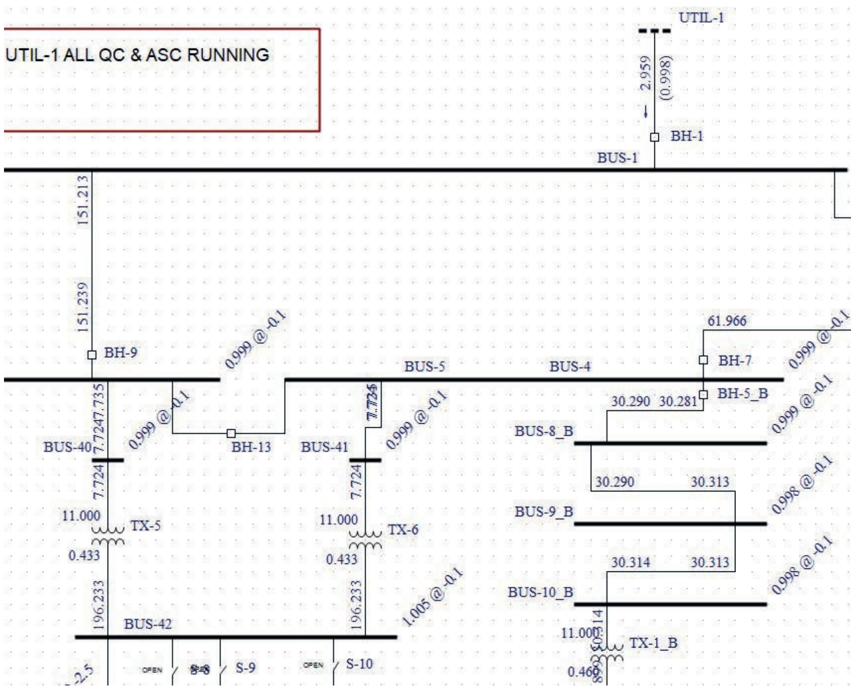

Fig. 1: EasyPower one-line diagram with Power Flow output

H(n)	Current (Amps)		Voltage (%V)	
	Local Utility	*IEEE-519* $\left(\frac{I_{SC}}{I_L}:20\text{-}50\right)$	*Local Utility*	*IEEE-519*
2	3.67	10.87	0.100	3.0
3	3.07	10.87	0.125	3.0
5	7.77	10.87	0.529	3.0
7	4.30	10.87	0.410	3.0
11	4.48	5.435	0.671	3.0
13	2.83	5.435	0.501	3.0
17	1.32	3.88	0.306	3.0
19	0.94	3.88	0.242	3.0
23	0.81	1.55	0.253	3.0

Table 3. Local utility requirements vs. IEEE-519

H(n)	Current		Voltage	
	(Amps)	*Met*	*(%V)*	*Met*
2	1.198	OK	0.032	OK
3	1.485	OK	0.060	OK
5	4.656	OK	0.314	OK
7	2.741	OK	0.259	OK
11	0.418	OK	0.062	OK
13	0.169	OK	0.030	OK
17	0.015	OK	0.003	OK
19	0.010	OK	0.003	OK
23	0.005	OK	0.001	OK

Table 4. Case 1: Utility-1 and Utility-3 with 7 ASC and 4 QC

H(n)	Current		Voltage	
	(Amps)	*Met*	*(%V)*	*Met*
2	1.654	OK	0.045	OK
3	1.959	OK	0.079	OK
5	5.058	OK	0.341	OK
7	2.993	OK	0.283	OK
11	0.430	OK	0.064	OK
13	0.194	OK	0.034	OK
17	0.015	OK	0.003	OK
19	0.010	OK	0.003	OK
23	0.005	OK	0.001	OK

Table 5. Case 2: Utility-1 and Utility-3 with 12 ASC and 5 QC

of the local limits with IEEE-519 limits based on certain IL that falls in the current distortion limit of 7% (of IL) for lower order harmonics. Interestingly, even the worst-case current distortion limit per IEEE-519, i.e., 4% for lower order harmonics, is higher than the local utility.

C. EASYPOWER RESULTS

A detailed model was developed, with simulations performed using the EasyPower tool to extract harmonic contribution from individual crane systems, ASCs and QCs, and the harmonics injected at the PCC were observed with different crane loads connected. The one-line diagram consists of the QC systems connected to the 11kV bus with components such as cable, main and auxiliary transformer, boom, gantry, hoist and trolley drives, and second order harmonic filter with notch filter. In some cases, tuning reactors may be used to tweak the filter parameters. The performance of the custom design is summarized in Table 4 and Table 5 for two cases involving a different number of connected loads, with requirements met in both. The worst-case voltage THD was found to be 0.4711%, which is safely under the THD limit .

It is inferred from the two cases that as load increases, system's harmonic injection contribution also increases. To meet the stringent harmonic requirements that local utilities might have, and with expansion of the crane system at port terminals, a custom design of harmonic filter, such as a second order high-pass filter with notch filter, as used in the case study, would provide better performance as compared to the standard LCL filter. As load increases, the fifth, seventh, etc., harmonics start to become significant. A custom design equipped to reduce injection of fifth, seventh and higher order with a notch filter can be used to meet the limits when the standard LCL filter design might not and when it might affect the performance of other equipment, causing issues with heating, safety, reliability and maintenance.

III. CONCLUSION

To ensure power quality for all customers, grid operators are provided with recommended practices, standards and requirements to control harmonic injection. A comparative study shows that local utilities may have tighter limits than IEEE. This paper emphasizes the importance of custom design as compared to standard design of harmonic filters by presenting case studies depicting higher distortion in currents and voltages with increased loads, which is a challenge as the crane industry expands business and thus demands the operation of more electrical machines and non-linear loads to support engineering.

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ABOUT THE AUTHOR

Shashank Mathur joined TMEIC Corp. in 2018 as an associate application engineer specializing in project system requirements and specifications for industrial projects, with a focus on port crane systems. Prior to joining TMEIC, Shashank worked at ABB Inc. as a power electronics intern with a research focus on soft-switching converters for low-voltage industrial motor drives.

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Tel: +1-540-283-2000
Fax: +1-540-283-2001
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