A GUIDE TO SUCCESSFUL ACCOMMODATION OF MASS PENETRATION OF HIGH INRUSH CURRENT DEVICES ON DISTRIBUTION NETWORKS

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ABSTRACT

Residential and/or small commercial devices that commonly demand high-inrush-power during starting are not new to electric utilities. What is new, however, is the mass deployment of such devices on the distribution grid due to government incentives and increased desire by the public for energy efficiency. These devices include but are not limited to the following: air conditioners, heat pumps, various types of commercial compressors, power tools, and on-demand water heaters. Air conditioners have been around since the early 1900s and they, along with heat pumps, are already used extensively throughout many parts of the south-western United States. As thermal conversion technology improves, the heat pump is quickly becoming the climate control device of choice in colder climates where it can be used for heating during the winter months and cooling during the summer months.

Before utilities can reasonably support widespread use of such technologies, we need to fully understand the true energy performance, the impact on customer power quality and utility equipment, and the lifetime projected costs of implementation. In the case of large compressors inherent within heat pumps, air conditioners and various small commercial processes, utilities are already absorbing the costs of upgrading the distribution infrastructure to handle the increased capacity required for short-duration motor starts. The inrush during start-up of these devices can cause voltage sags on the utility system, which may be severe enough to damage equipment components.

SUMMARY

This project investigates the effects of mass deployment of high-inrush devices by (1) documenting the information on this subject available in the pertinent literature, (2) developing realistic computer models of distribution systems with a large penetration of inrush devices, and (3) investigating the impact of these devices and the effectiveness of mitigation measures available to utilities and utility customers in simulations.

The literature search portion of this report provides comprehensive information on many aspects pertinent to the deployment and presence of high-inrush devices in distribution systems including (1) information on residential and commercial level energy efficiency initiatives and consumer trends, (2) a review of the technology of devices that produce inrush currents on distribution systems, (3) a review of the different compressor technologies employed in high-inrush devices, (4) information on utility concerns caused by increased penetration of high-inrush current devices, (5) information on the characteristics of the inrush produced during start-up of the commonly used high-inrush devices, and (6) documentation of mitigation techniques that are available to reduce or suppress power quality issues due to increased penetration of high-inrush appliances. Figure 1 shows inrush current measured during start-up of a residential heat pump. The measurement was done as part of the effort to characterize the inrush produced by various devices.

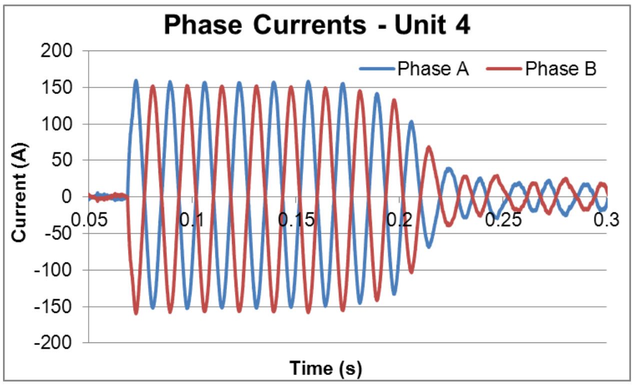

Figure 1: Measured inrush current during startup of a residential heatpump.

For the simulation portion of this project, the impact of high-inrush devices on the secondary distribution network (at the utility customer level) and the primary system (the utility distribution system) was investigated.

For the investigation on the secondary network, a case study on a real-world secondary distribution network that served 17 customers and that experienced flicker problems due to high-inrush devices was conducted. A detailed transient model of a typical compressor used in modern heat pumps and air conditioners was developed. The developed inrush device model was integrated into a model representation of the secondary system. Figure 2 compares the voltages measured at the customer site with the model-predicted voltages. The comparison shows that the developed model accurately reproduces the voltage drop measured during start-up of the heat pump.

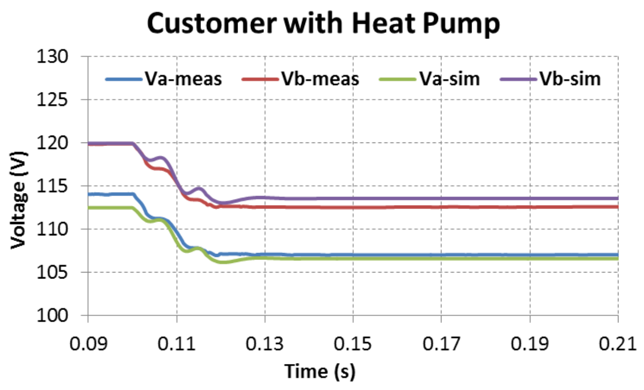

Figure 2: Comparison of measured and model-predicted voltages during start-up of a heat pump.

The verified model was used to investigate the impact of multiple high inrush current devices and the effectiveness of three mitigation measures: (1) utilizing a soft-start device, (2) utilizing a hard-start device, and (3) increasing the size of the service transformer and/or secondary network side conductors.

For the investigation on the primary voltage level, a case study was presented of a real-world primary distribution system, provided by Hydro Ottawa, which experienced problems due to a delayed voltage recovery. The bulk of the effort for this case study went into creating and sanity checking the large distribution system. An OpenDSS model of the system that explicitly models each of the 3834 lines, 1793 transformers, and 1968 loads in the Hydro Ottawa system (see Figure 3) was created.

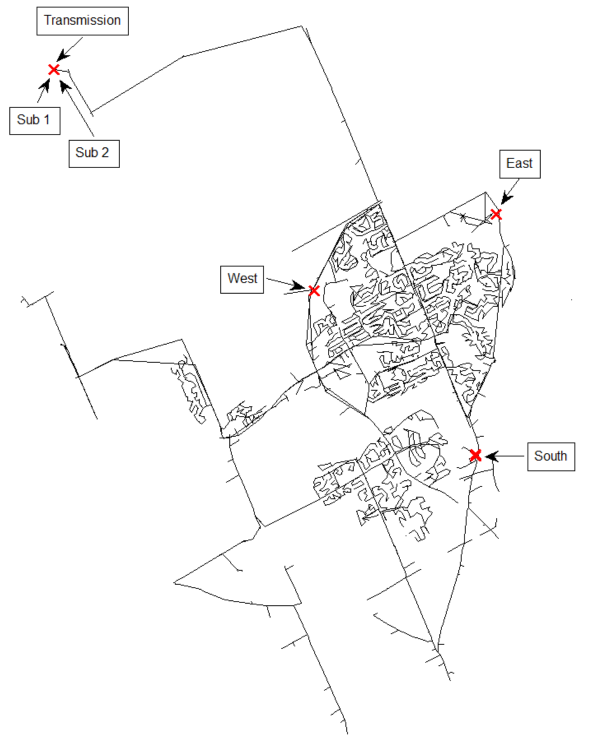

Figure 3: Illustration of developed feeder model.

The OpenDSS system model was employed for some preliminary simulations to show voltage drops and magnitude of voltage sags on different parts of the feeder for various degrees of high inrush device penetration levels. The constructed system model is intended to be used for further investigations in future phases of the project.

For the investigation on the impact of system events on high-inrush devices, a dynamic single-phase induction motor model that is based on a 3.5 ton air conditioner was built. Specific events simulated include various voltage sags and surges, low-frequency voltage oscillations, and capacitor bank switching.

The report concludes with a section that provides answers to some of the questions and concerns brought forth by the representatives of project sponsoring utilities during the course of the project. The sections include a simplified circuit to estimate the required minimum ratio of the available short-circuit current to the maximum value of load inrush current at the point of load connection.

SIMULATION RESULTS AND CONCLUSIONS

The simulation results from the case studies that evaluated the impact of multiple high inrush current devices on the secondary system show that soft start and reconstruction approaches effectively reduce flicker issues by reducing voltage sags/dips at locations surrounding the operating unit. On the other hand, the hard start mitigation option tends to reduce the inrush time during a start-up, but fail to reduce the voltage sag/dip. The effectiveness of the mitigation options are illustrated in Figure 4 and Figure 5 for simultaneous start-ups and consecutive start-ups, respectively. The figures show that simultaneous start-ups results in higher flicker values compared to consecutive start-ups. In addition to the number of individual inrush devices on the system, flicker levels are dependent on feeder characteristics, load distribution and measuring points.

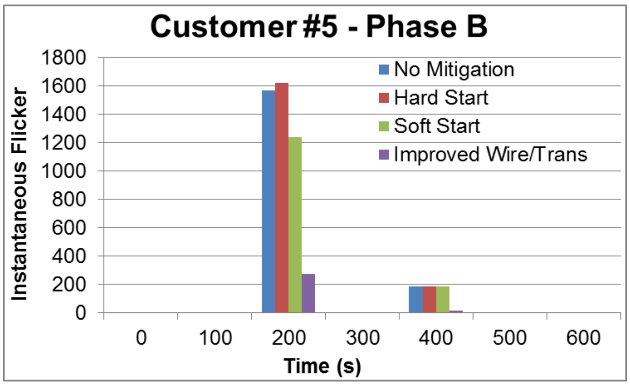

Figure 4: Flicker during simultaneous starting.

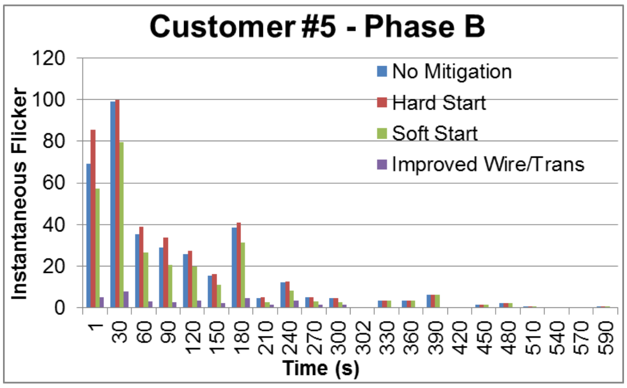

Figure 5: Flicker during consecutive starting.

The simulation results show that a voltage sag to below 0.6 pu for 10 cycles or longer caused motor stalling. For the investigation on the impact of abnormal oscillations on high-inrush devices, the voltage was varied between 90% and 110% of the nominal value and considered three different frequencies of oscillation - 0.1 Hz, 0.7 Hz, and 2 Hz. The simulation results show that the motor is not stalling in any of the three cases. The real power is relatively insensitive to the voltage oscillations while the reactive power was impacted significantly and fluctuated by as much as 0.40 per unit (pu). The simulations that investigated the behavior of an inrush device during a capacitor bank switching event showed significant fluctuations in the real and reactive powers and the rotor speed; nevertheless, the machine recovered to its steady state condition. The impacts of voltage and current harmonics are qualitatively discussed – it is generally believed that harmonic levels below the IEEE Std. 519-1992 [1] harmonic limits will not damage or cause misoperation of inrush devices.

Table 1: Estimation of required short-circuit current

Maximum inrush current (A)	Minimum short-circuit current (A)	Short-circuit capacity (kVA)
70	1,750	420
80	2,000	480
90	2,250	540
100	2,500	600
110	2,750	660
120	3,000	720
130	3,250	780
140	3,500	840
150	3,750	900
160	4,000	960
170	4,250	1020

The simplified circuit was used to estimate the required minimum ratio of the available short-circuit current to the maximum value of load inrush current. In a worst-case scenario, this ratio was found to be 25. Additional results are summarized in Table 1. For a given inrush current, a utility could use this table to roughly estimate the required short-circuit current, and vice versa.

RECOMMENDATIONS

For future research, it is recommended to continue the study by utilizing the highly-detailed model of the Hydro Ottawa distribution system to investigate the issues listed below:

Investigating the impact of high-inrush devices on the utility system during normal operation for various penetration levels. This requires more sophistication in determining when the devices are turned on, that is, they are not all turned on at the same time but are rather turned on based on a stochastic pattern. This will result in a realistic simulation of the impact of high inrush devices on the utility system and will determine at which penetration levels mitigation measures are warranted.

Investigating the impact of high-inrush devices on the utility system during system restoration for various penetration levels and evaluating possible mitigation measures. These measures include (1) restoring the system in sections, (2) installing additional transformers, and (3) connecting to other sources.

Investigating fault-induced delayed voltage recovery on the Hydro Ottawa system. A detailed investigation of delayed voltage recovery must be performed in an Electromagnetic Transient (EMT) software application tool. An EMT-type tool allows for the inclusion of complex models of inrush devices.

ACKNOWLEDGEMENTS

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REFERENCES

Extracted from CEATI Report T114700-5155 "A Guide to Successful Accommodation of Mass Penetration of High Inrush current Devices on Distribution Networks." Complete list of references in the full version of the report.