DFR MONITORING OF TRACTION BATTERY CHARGER PERFORMANCE

Shahin H. Berisha
GateWay Community College
Phoenix, AZ

Garrett Beauregard
Electric Transportation Engineering Co.
Phoenix, AZ

John Demcko
Arizona Public Service Co.
Phoenix, AZ

Ben Tremerie
LEM Instruments
Ballston Spa, NY

ABSTRACT: The operation of the traction battery charger was interrupted periodically due to the disturbances on the supply ac three-phase voltages. The three-phase line-to-neutral voltages and dc bus voltage were monitored for a period of over 10 weeks. Voltage waveforms are captured every time when disturbance, over or under voltage occurred. Charger operation was recorded by monitoring dc bus voltage. The paper present the summary of the data collected, lessons learned and suggestions for further improvements and enhancements.

INTRODUCTION

Electric Transportation Engineering Corporation (eTec) is a privately held Arizona Corporation headquartered in Phoenix, Arizona. eTec was incorporated in 1996 to support the development and installation of battery charging infrastructure for electric vehicles. eTec's sister company Electric Transportation Applications was incorporated in 1989 to provide technical support and testing services for the electric vehicle industry.

The eTec staff consists of 10 technical and professional personnel possessing 100 years of work experience, with 30 years of experience specifically associated with electric vehicles and electric vehicle infrastructure.

eTec and ETA conduct basic research into battery fast charging and fast charge algorithms. Using the information gathered from its research, eTec developed charge systems using the patented SuperCharge algorithm. eTec holds exclusive patent rights to use the SuperCharge algorithm in its products, allowing faster charging with less heat generation and longer battery life than any other fast charge algorithm available. eTec offers SuperCharge systems specifically engineered for airport ground support equipment operation and for neighborhood electric vehicle operation. These systems incorporate the patented SuperCharge algorithm and provide a complete engineered solution to battery charging.

As a licensed contractor, eTec can also provide complete installation services. eTec can provide engineering and construction services, ensuring a turn-key installation of your charging infrastructure.

In addition to its line of SuperCharge systems, eTec is a distributor for several lines of Level 2 (medium power) chargers. Of course, eTec also provides installation services for Level 2 chargers and is an authorized installer for Daimler-Chrysler and Ford Motor Company products.

DESCRIPTION OF THE TYPE 25AFE CHARGER

The heart of the device is a 33kW switching power supply used to charge and discharge traction batteries. It is capable of delivering (or absorbing) up to 400 Amperes of current and can operate at voltages as high as 450VDC. The charger is powered from a 480VAC, three-phase circuit with a maximum current draw of 51A. **Figure 1** is a functional block diagram of the charger and its typical connections.

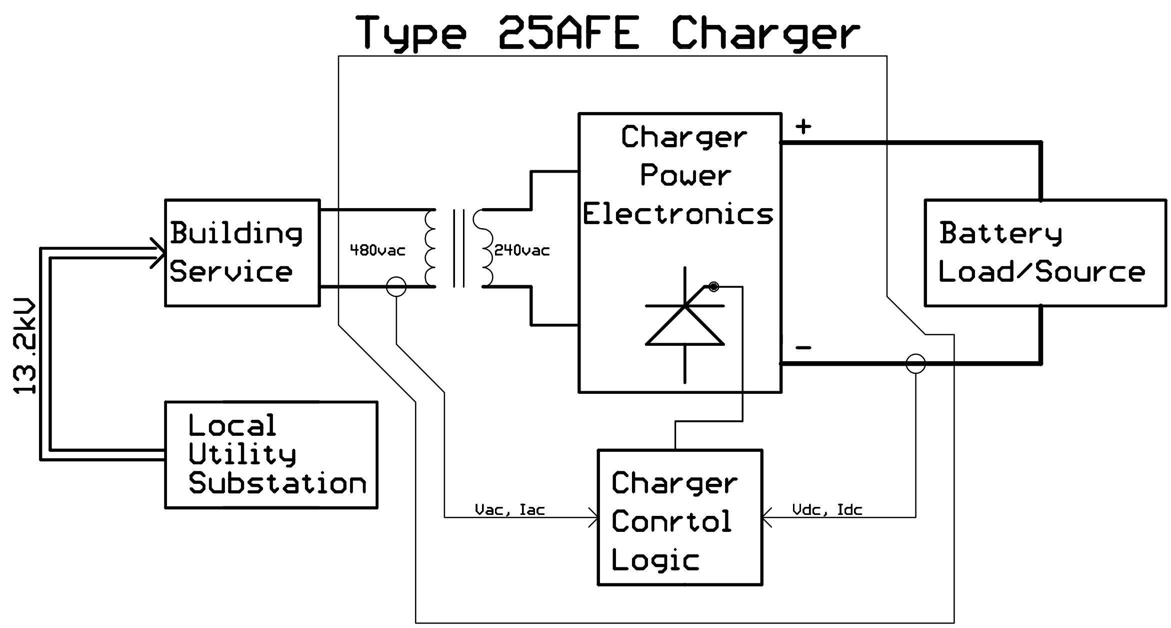


Figure 1

An isolating transformer (45KVA, 3 Ø, isolated, 480Δ primary, 240 Δ secondary, 60Hz) operates at a primary line voltage of 480VAC with secondary voltage at 240VAC. Besides providing the proper voltage to the power electronics section, the transformer provides galvanic isolation from the power system. Insulated Gate Bipolar Transistors (IGBTs) are used as the power conversion elements. In normal charging operation, they maintain a DC bus voltage of 450V. The microprocessor based control system for IGBTs insures near unity power factor and minimizes harmonic distortion on the AC input line. IGBTs are also employed for the DC output system. These operate in a pulse width modulated mode (PWM) at a maximum frequency of 10kHz to regulate the current delivered to (or discharged from) the traction battery. A charger control module monitors ac input voltage and current as well as dc voltage and current. It contains the firmware logic required for charger operation, protection and alarm/control functions.

DESCRIPTION OF THE PROBLEM

Chargers are evaluated on a 24/7 basis at this eTec facility. Typically the 25AFE chargers would be run overnight to charge or discharge a battery pack. On several occasions, the type 25AFE charger would be found in the morning shut down with the "*fault*" alarm on the control panel active. In the context of the charger, "*fault*" means that an unusual condition was encountered that could damage the charger. The charger is equipped with logic that monitors the secondary voltage of the isolation transformer. When the 25AFE is in the discharging mode, energy is removed from the traction battery, converted to AC current and injected into the utility system grid. If a fault (i.e. short circuit or voltage dip on the distribution system) occurs on the line side of the charger, the discharge energy would be trapped in the equipment. If the voltage dip persists for too long, the charger interprets this as loss of an AC sink and shuts down. Otherwise, the trapped energy may cause damage to the charging system. When the monitoring system detects an over-voltage condition (greater than 15% of nominal voltage) at the transformer secondary, it sends a signal to the charging control system that curtails the discharging process in a safe manner.

The line monitor is always active, regardless of the mode of operation of the 25AFE (i.e., charge or discharge). When the line monitor triggers a shutdown, the result is a loss of DC bus regulation. This, in turn, causes the bus voltage to drop from 450VDC to approximately 340VDC. The presence of large filtering capacitors on the DC bus causes a very slow rate of voltage decay. A bleeder resistor is mounted on the DC bus to discharge stored energy from the capacitors when the system is shut down.

The charging equipment is installed in downtown Phoenix near one of the utility's 13.2kV distribution substations. The distribution system was thought to be quite robust in this area and not a candidate for voltage dip problems. Line voltage in the area is always near the upper limit of the acceptable voltage range (usually ±10% of nominal).

DFR INSTALLATION

Given the frequency of type 25AFE charger shutdowns, it was determined to install monitoring device(s) to either confirm or refute the theorized root cause of the charger shutdown. With the assistance of the local utility (and their DFR vendor), a 16 analog channel/32 event channel DFR was supplied to help quantify the problem. The DFR was configured to monitor on four analog channels. Three channels monitored the secondary voltages of the charger's isolation transformer. The fourth channel monitored the DC Bus Voltage at the DC bus bleed resistor.

THE PURPOSE OF THE DATA COLLECTION

The charger equipment is energized and in-use around the clock. At various times, the charger was found in an idle state with a *fault* indicated on its control panel. The theory was that a disturbance in the line voltage caused the charger's line monitoring device to shut down the charger and triggered a fault indication. This assumption had to be proved by monitoring the system voltages for eventual disturbances in their waveforms. It was theorized that the charger faulted at the moment when the disturbance occurred. If this theory could be confirmed, it might be possible to desensitize the charger (by software/firmware modification) to the voltage dips that are inevitable even on relatively stiff distribution systems. This method had been applied successfully at other locations in the utility's service area[1].

Before a DFR was available, initial data was taken using a National Instrument LabView Virtual Instrument (VI) that collected line voltage data. The VI was run on a notebook computer based

National Instruments data acquisition card (DAQ card). This data showed that there were voltage disturbances coming from the power system. This was indicated based on the values of total harmonic distortion monitored for three voltages. The data also indicated that there is a need to capture waveforms during the voltage disturbance. The problems typically associated with this sort of instrumentation were encountered, specifically:

- Lack of channel to channel isolation
- False triggering
- Failure to Trigger
- PC Lockup
- Equipment not suitable for unattended operation

In this application, a digital fault recorder (DFR) was the best candidate for long-term data acquisition. A DFR was installed to collect data for the period between August 30, 2001 and October 09, 2001. Transformer secondary three-phase to neutral voltages and the dc bus voltage were monitored. Trigger points were set at 5% over voltage and 5 % under nominal secondary voltage. During the 10 weeks period, 130 events were recorded. Only three events recorded coincided with the charger going into the idle (*fault*) mode.

TRIGGER MODES IN DIGITAL FAULT RECORDER

The DFR monitors the signals (three ac voltages and one dc voltage) continuously, but the data is stored only when one of the preset trigger events occurs. The trigger events set to 5% over-voltage or under-voltage in any of the ac lines or in the dc line. Recorded duration upon trigger is set to 100 msec pre-fault and 500 msec post-fault. These times were deemed adequate for comparison of pre-event and post-event data.

FAULT DATA

During the observed period, there were three recorded events in which charger faulted into the idle mode. Table 1 shows times when these faults occurred.

Table 1

	FAULT #1	FAULT #2	FAULT #3
Date	8/1/2001	9/5/2001	9/14/2001
Time	6:19PM	6:02AM	5:56 PM
Duration in ms	40	25	60

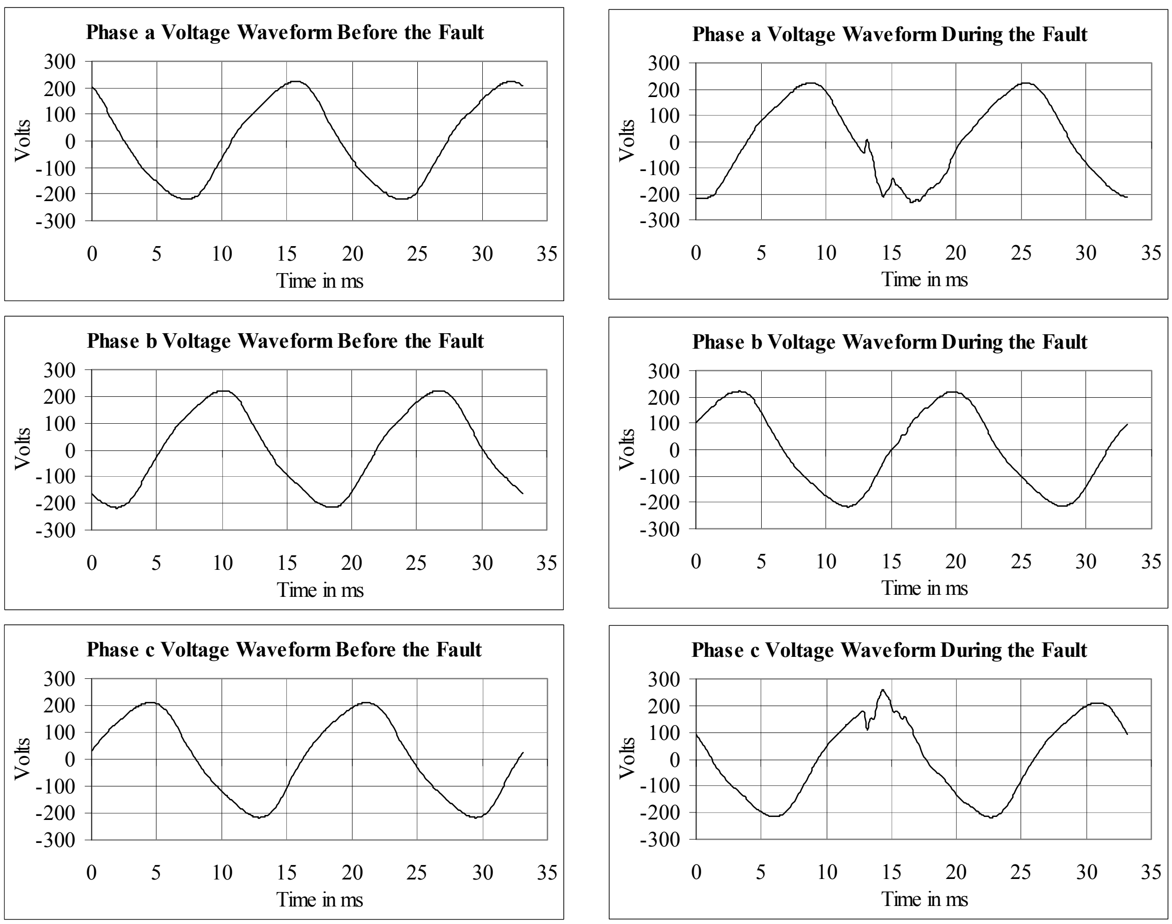
Two out of three faults occurred around 6:00 PM and one fault occurred around 6:00 AM. **Figure 2** shows voltage waveforms captured during the fault # 3.

Figures 2 shows that the power system disturbance occurs only on the on the first and third phase of the system. This indicates a load connected on these two lines. Disturbance occurs on the same two lines in the case of other faults also.

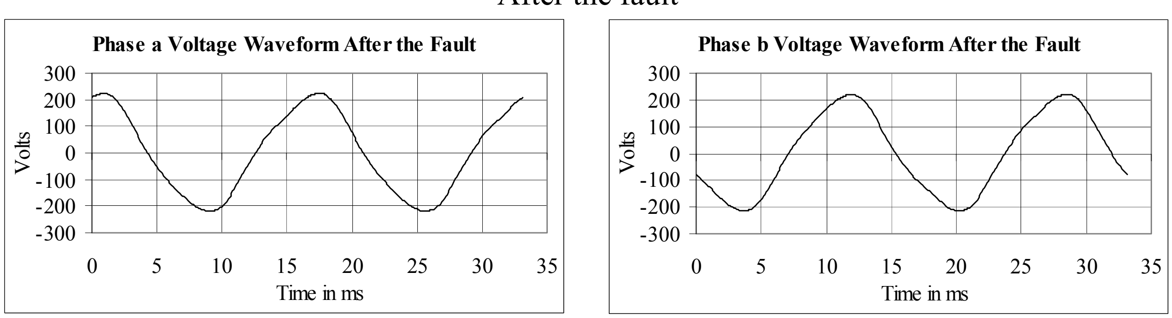
In **Table 2**, the cumulative data for the three faults recorded are given. The data show the RMS and Peak values and total harmonic distortion for three line-to-neutral voltages. **Table 2** shows pre-fault, fault-concurrent and post-fault data. Comparison of these data shows no difference on the RMS values of three phase voltages. Comparison of THD shows 100 % increase on phase “a” and phase “c” during the fault. On the same two phases there is an increase of up to 22 % in the peak voltage value. No change was recorded on phase “b”. **Figure 2** shows change in phase “a” of THD and peak voltage.

Before the fault

During the fault



After the fault



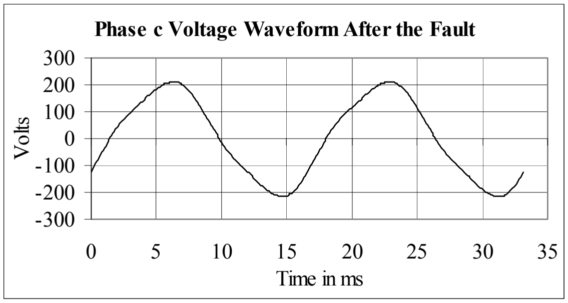


Figure 1. Phase voltage waveforms before, during and after the fault.

TABLE 2

		Phase RMS Values			THD			Peak		
		a	b	c	a	b	c	a	b	c
		V	V	V	%	%	%	V	V	V
Fault # 1	Pre	152.47	148.86	145.77	7.90	8.50	8.60	226.53	221.93	211.19
	During	152.46	148.84	145.73	15.30	8.30	16.30	245.69	222.31	253.36
	Post	151.07	147.34	144.51	7.90	8.50	8.70	224.99	220.39	210.43
Fault # 2	Pre	150.60	146.85	145.38	7.80	8.30	8.40	221.93	219.24	209.66
	During	150.71	147.75	146.03	10.30	8.40	10.70	240.33	221.54	239.18
	Post	151.25	147.98	146.62	8.20	8.60	8.80	224.99	222.31	220.78
Fault # 3	Pre	152.53	149.10	146.17	8.10	8.50	8.40	224.23	220.78	210.04
	During	151.82	147.99	144.49	12.30	8.40	14.30	233.43	220.01	257.19
	Post	150.93	147.55	144.70	8.60	8.60	8.70	221.31	200.46	216.56

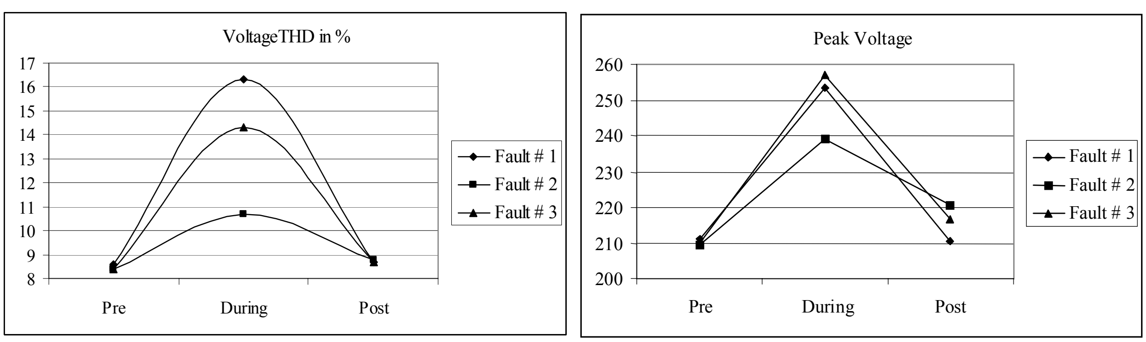


Figure 3. Variation of voltage THD and peak voltage during the faults

Figure 3 shows clearly increase in THD and Peak voltage for Fault # 3.

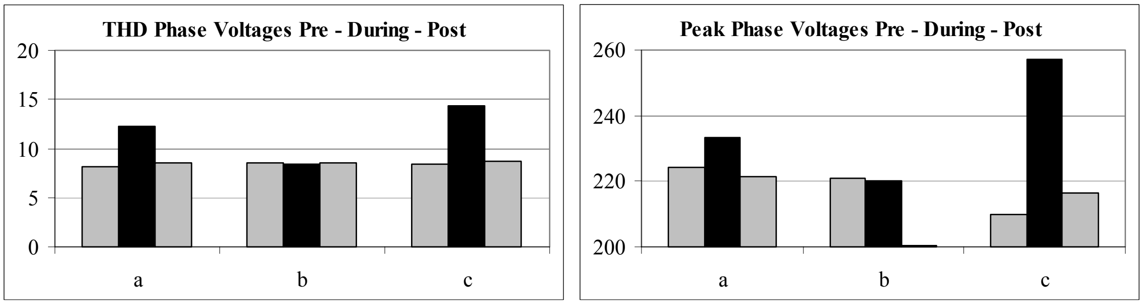


Figure 3. Voltage THD's Pre, During, and After the Fault for Fault # 3

The behavior of the charger's dc voltage before, during and after the fault is documented in **Figure 4**.

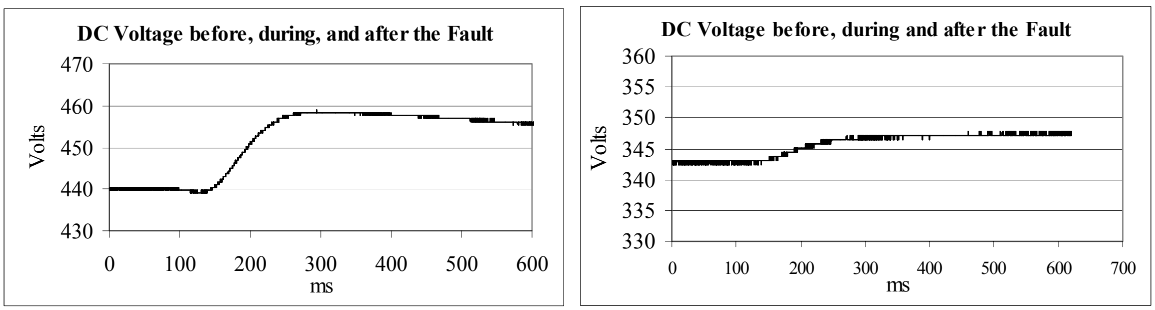


Figure 4. DC voltage before, during, and after the fault

As a result of disturbance on the ac side of the charger, dc voltage increases by approximately 20 V within first 120 ms after the fault. Following the brief rise, it drops to about 340 V and remains there indefinitely. This voltage drop to 340 V is not shown in **Figure 4** because of the length of the records (the drop from 450V to 340V takes up to one minute). This voltage value indicates the fault on the charger. A physical reset is needed to reactivate the charger.

As an indication that dc voltage drops at 343.11 V is the very next record that occurred next day at 8:56 AM. The disturbance on the ac side in this case has no impact on the charger because charger is already in Fault mode (as indicated by the DC voltage signal already at 340V at the beginning of the fault). Variation of dc voltage during this record is also shown in **Figure 4**.

CONCLUSION AND LESSONS LEARNED

The data collected using DFR indicate that charger is being adversely affected by voltage dips from the utility power system. The amount of data collected was not sufficient to identify the exact nature of the transient that caused the 25AFE charger to fault. Further data collection and monitoring is needed to pin-point the source of interference. An alternate approach is to modify the software logic that makes the charger sensitive the to the voltage dips, sags and swells that are inevitable on a real world power system. It may be possible to co-ordinate the charger software with the CBEMA curve and still avoid damage due to entrained energy.

The number and types of chargers in the metro Phoenix area is expected to proliferate significantly. It would be a great disservice to the electric vehicle industry to expose the general pubic to charging systems that are overly sensitive to power quality phenomena. To that end, we anticipate increased and prolonged DFR monitoring of charger performance. The information obtained from this effort will be used to enhance the real world performance of the next generation of chargers and, if warranted, document deficiencies in the utility supply.

REFERENCES

1 "*Power Quality Problems And Solutions At Arizona Public Service Company*", J.A. Demcko and S. Sullivan. Presented at the 7th International Conference On Harmonics and Quality Of Power, Las Vegas, Nevada, October 16-18,1996.