CHAPTER 12 – ELECTRICAL ASSESSMENT

12.1 Introduction

The purpose of this assessment report is to assist GWA with identifying, correcting and developing procedures to safely operate and maintain its electrical system, which is a vital component in providing water and wastewater services for the people of Guam.

Standard investigative techniques were used to identify and locate the sources of the electrical challenges plaguing the consistent operation of GWA services. These included meetings with GWA personnel and GPA representatives; field observations of personnel during equipment troubleshooting, repair, removal and installation; site observations and application of power quality and infrared test equipment; and analysis of collected data and digital photographs. The findings indicate the following primary contributing factors affecting GWA services:

- **Service Voltage Variation and Unbalance at Water Wells** – These two were predominant at the Northern Water District, with minor occurrences in the Central District. The wastewater stations in these two districts were also affected but, since the pumps operate for short time periods, the voltage effects were minimal.

  This condition is largely due to the stations being located in residential subdivisions where a mixture of single- and three-phase circuits exists. Electrically balancing these single-phase circuits with GPA, together with installing improved pump motor protection devices and voltage unbalance relays at the auto transfer switches, will solve most of the water well failures.

- **Frequency of Operation and Installation of Wastewater Pumps** – Frequency of operation of the larger horsepower motors increases the mechanical wear on the motor components, such as seals, bearings and shafts, in addition to producing inconsistent hydraulics and flows. This is particularly true when full-voltage motor starting is used.

  Replacing these motor drives with variable speed or electronic soft starters will improve the process flow and minimize the equipment wear. Because variable speed drives are of greater complexity, skilled, trained personnel are essential to their operation and maintenance. Proper piping installation practices and alignment will limit mechanical failures.

- **Lack of Condition Monitoring System** – Continuous system status and alarm condition information has not been available to operations personnel. Failure conditions have been reported by the public rather than being detected by GWA.

  A SCADA system provides the vital link to effective deployment of resources and is the initial step toward achieving a predictive maintenance program.

- **Lack of Predictive and Preventive Maintenance** – Preventive maintenance has generally consisted of replacing failed equipment with new equipment. In a few cases, the failures have been frequent, with the same installation procedure or equipment used each time. Although predicting when equipment will fail is not an exact science, great strides have been made toward development of diagnostic tools. In the hands of trained personnel, these tools can minimize unplanned catastrophic failures and allow for better scheduling of resources.

Infrared imaging techniques were used during this assessment to locate and (combined with the efforts of maintenance personnel) to prevent several instances whereby an electrical failure would have occurred within a three-month period. Besides its use on electrical systems, infrared imaging can be used on mechanical and hydraulic systems as well to detect leaks, mechanical wear and other conditions.

Many of the concepts and practices are also found in the National Fire Protection Association publication titled NFPA-70B – Recommended Practice for Electrical Equipment Maintenance and in Institute of Electronic and Electrical Engineers (IEEE) publications. These standard practices should be incorporated in GWA's electrical program.

- **Personnel Training** – The skill level of personnel in the areas of troubleshooting and analysis varies. Skills have usually been acquired through individual prior experience and training at other facilities or agencies.

  Training in such skills as reading blueprints and schematic diagrams, troubleshooting, understanding electrical codes and standards and basic electrical theory and principles is essential to continuous personnel development.

- **Electrical Safety and Building Security Issues** – Water and electricity do not mix. Water in the electrical and generator rooms, whether through leaks from the diesel line wall penetration or from empty raceways, must be repaired. Building security is also a concern since unauthorized persons have vandalized several stations, as well as the interior of dangerously "live" electrical equipment.

  Electrical work practices and standards as found in NFPA-70E – Electrical Safety in the Workplace provide guidelines for implementation and compliance.

In addition to the observations and findings summarized above, this chapter includes recommendations for improvement and implementation of actions relating to these major issues.

GWA and GPA have made progress in addressing several of these items. An example is Station Y-15, which has been a source of numerous failures in the past. Balancing the voltage, improving the surge protection system at the power pole and station and improving the motor protection devices will ensure a longer life for this well and water supply.

It is anticipated that this assessment is a step in the development of the electrical component of an overall WRMP and will assist in the reallocation of material and personnel resources to achieve GWA's goal of providing "long term value while meeting Guam's vision for growth and development in a sustainable manner."

12.2 Existing Electrical System

12.2.1 GPA System

The service distribution voltage provided by GPA is 13,800 volts, three phase, three wire. This system is grounded at the GPA substation transformer; however, the ground or neutral conductor is not extended beyond the substation. Any ground faults would rely on the circuit impedances back to the substation.

Overhead conductors with wooden cross arms on concrete poles are used at most locations. At a few locations, however, wooden poles are still in use.

The predominant service voltage used at the various stations is 480 volts, three phase, three wire, supplied through pole-mounted transformers. In cases where the primary electrical system is installed, underground, pad-mounted transformers are used. The transformer neutral was either grounded or ungrounded. A set of lightning surge arresters are installed at almost all of the overhead transformer pole installations to protect the equipment downstream. These are installed in line to ground.

12.2.2 Water Wells

The electrical system at the deep water wells is composed primarily of two types of installations. For metering purposes, the larger stations, 75 hp and larger, involve the use of current transformers while those less than 75 hp use a self-contained meter socket. The metering is usually located on a pedestal or masonry wall separate from the station building. In a few instances, the metering and service masts are embedded in a concrete pedestal.

Almost all of the water wells are backed by a standby generator. In a few instances, one generator is used to power two wells or two sites. Most of the generators are owned and maintained by GPA.

12.2.3 Water Booster Stations

These stations generally consist of two or more booster pumps that are powered through a motor control center or panel and backed by a standby generator through an automatic transfer switch. The predominant voltage is 480 volts, three phase, three wire, although the smaller stations are powered at 240 volts, either single or three phase.

The metering for these stations is primarily pedestal-mounted, either self-contained or through the use of current transformers. Most of the water booster stations visited have generators that are owned and maintained by GPA.

12.2.4 Wastewater Pump Stations

Most of the wastewater stations are powered through the GPA service at 480 volts, three phase, three wire, ungrounded. The larger stations are powered through a pad-mounted transformer. Equipment power is received through the building service metering, a station main breaker, an automatic transfer switch and a motor controller or panel.

At several stations, a separate integrated pump control panel is installed, which uses floats, electro-rods, or bubbler system level sensing. A few stations use a float switch to back up the bubbler or electro-rod sensors. The integral pump and motor combination has been replaced with dry pit, submersible-type units.

These stations are equipped with generators predominantly owned and maintained by GWA, although several stations are powered by generators that are owned and maintained by GPA.

12.2.5 Water Treatment Facility

The Ugum WTP, along with the associated river pump station, is powered at 480 volts, three phase, four wire, through pad-mounted transformers at each site.

Power is distributed through a distribution switchboard and motor control center located at the service generator room and the main control room. Both the switchboard and the motor control center are backed up by standby generators owned and maintained by GWA.

12.2.6 Wastewater Treatment Facilities

The wastewater treatment facilities are powered at 480 volts, three phase, three and four wire systems through pad-mounted transformers and a distribution switchboard located within or adjacent to the generator room.

Most facilities have their power to the motors distributed through a motor control center. In the larger plants, the motor control centers are distributed throughout the facility. The standby generators are generally owned and operated by GWA.

12.3 Assessment Methodology

The first step in preparing this assessment report was to collect electrical data using power-analyzing test equipment. The electrical parameters of voltage (line to line and line to ground), line current, voltage and current unbalance, power, energy and power factor were recorded with an AEMC Model 3945 Power Quality Analyzer. Both instantaneous and short-term (15- to 60-minute windows) readings were compiled and are detailed by water and wastewater station in Appendix 1K.

Infrared imaging techniques were also used to observe the electrical system in operation and to identify any "hot spots." Infrared imaging is a common preventive and predictive maintenance tool used to locate abnormal electrical terminations and other heat-generating sources. An Infrared Solutions Thermacam was used for this purpose and the recorded images were saved in jpeg format. During this process, several major abnormalities were observed and, in those cases where the electrician was present, they were immediately corrected. Additionally, vibration readings were made on randomly selected operational motors that were accessible.

Digital photographs of the electrical equipment and sites visited are included in Appendix 1K. A few sites, those not formally covered by this report, were casually visited. Several sites were visited more than once over the course of the assessment; with consequent photographs of these sites showing improvements or replacement of equipment.

Based on the data compiled, an assessment ranging from zero through 4 was assigned to the various components of the operating system. Each component was assigned a weight that, when multiplied by the assessment value, would give a weighted average component. Table 12-1, Assessment Rating Scale defines these ratings.

Table 12-1 – Assessment Rating Scale

System Rating	Description of Equipment State
0	Required equipment is missing or not present. Equipment is not operating or repairable. New equipment is required.
1	Equipment is present but in poor condition. Equipment is not operating but may be repairable. If repaired, it probably has a short remaining life.
2	Equipment is present and in fair condition. Equipment may be operational but require other elements of the system to be functional. Equipment requires maintenance and repairs.
3	Equipment is present and in moderate condition. Equipment is operational. Routine maintenance being performed.
4	Equipment is present and in like new condition. Equipment is operational and newly installed.

A holistic approach was used to arrive at the weighted average for each station or plant. For water and wastewater pump stations, consideration span the electrical service derived from the GPA service pole or transformer bank to the electrically driven load. This include the electrical conductors and metering, the building main disconnect and the standby generator and transfer switch.

For the treatment facilities, the assessment covered distribution boards and specific equipment such as the motor and motor drive. The assessment value in these cases is the average value without weighting for each piece of equipment. Because each piece of equipment contributes to the operation of the plant, the average of all equipment was calculated and represents the value of the facility. A tabulation of the station assessment in located in Appendix 1K.

12.4 Electrical Observations and Findings

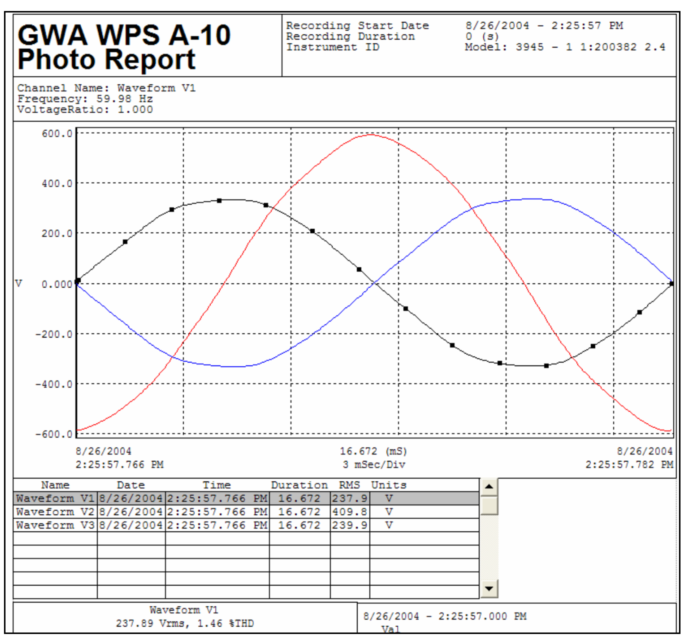
In a review of the collected electrical data, site observations, personal interviews, work practice observations, photographs and manufacturer inquiries, the following issues have been identified as pertinent to the development of the electrical master plan. Although most of the issues and examples relate to the deep well electrical system, the principles apply to all facilities.

12.4.1 Electrical System Power and Grounding Discussion

The primary source of electrical power for the GWA facilities is through GPA transformers. Most of the station transformer banks are connected using a DELTA configuration. This configuration is normally connected ungrounded.

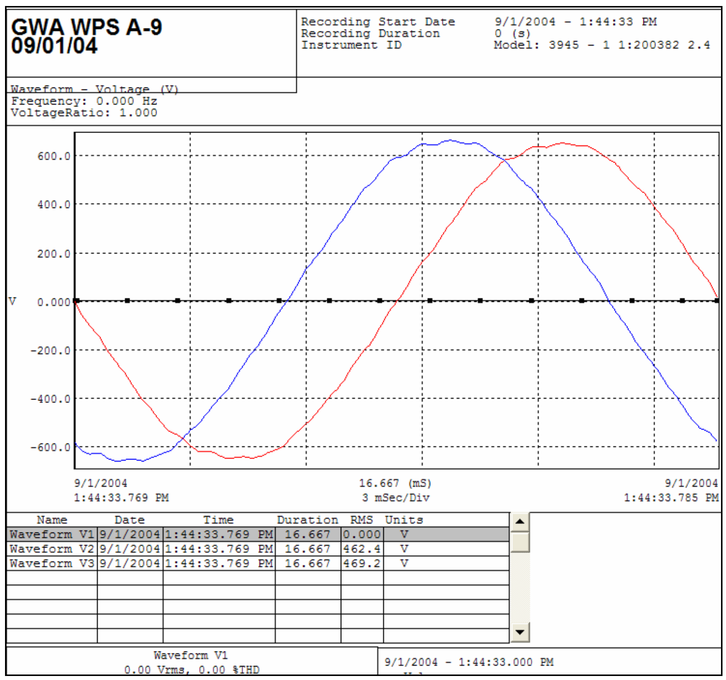
A few stations were connected using a WYE configuration. These connections were predominantly ungrounded, although this system could be easily grounded. A few of the DELTA-configured stations were observed to be grounded at the center tap of one of the transformers. This configuration, however, places a high degree of electrical stress on one of the phase conductors to ground (416 volts versus 277 volts, or approximately 50% more). Figure 12-1, Transformer Center Tap Grounded Voltage – Station A-10 depicts the unbalance at Station A-10.

Figure 12-1 – Transformer Center Tap Grounded Voltage – Station A-10



DELTA-configured transformer banks are typically used in industrial processes where experienced personnel are employed. An advantage of this configuration is that during a failure of one of the transformers the process could continue to operate in an open DELTA configuration. The conductors are coupled to ground using the system capacitance and can be measured using a high impedance meter. If the coupling is the same, the voltage to ground will be equal. If one of the phases starts to become grounded, the voltage will shift so that, at worst case, the voltage will be 480 volts to ground for the ungrounded phases and zero for the grounded phase. Figure 12-2, Grounded Phase-to-Phase Voltage Recording – Station A-9 presents a plot of this condition at Station A-9.

Figure 12-2 – Grounded Phase-to-Phase Voltage Recording – Station A-9



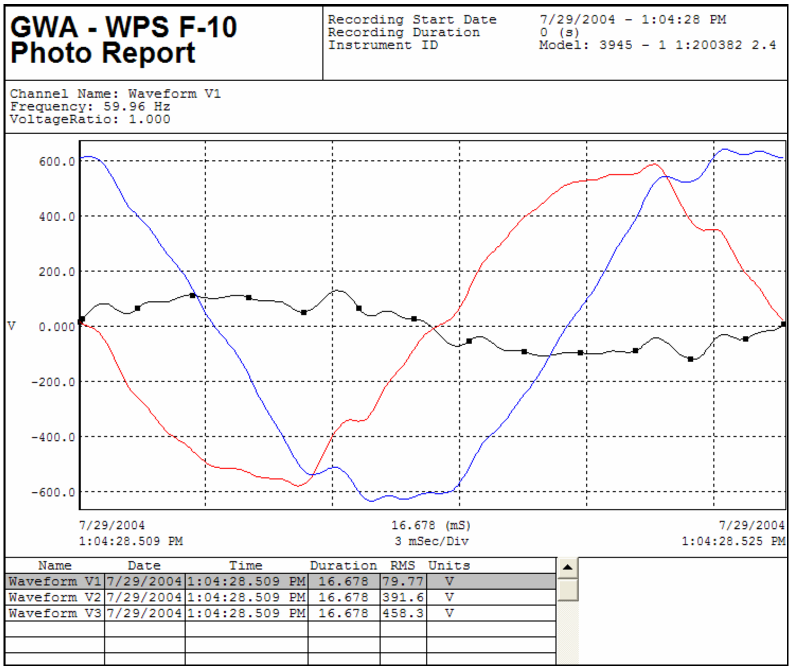
Because of this capacitive coupling, a resonance condition could exist where high transient voltages could develop. This was observed at Station F-10, where the voltage to ground was measured at approximately 700 volts with the station main breaker in the open position.

A solidly grounded system (WYE-connected and grounded transformer bank) would yield voltages to ground in the 277-volt range. This would limit any transient voltages to ground and improve the effectiveness of transient surge suppressors.

In accordance with Article 250.21 of the 2005 National Electrical Code, a means to detect the grounding of an ungrounded system is required. This is because the second ground fault will yield a phase-to-phase fault that increases the damaging effects of a short circuit. No method of indicating a ground condition was installed at any of the sites visited. The recording instrument AEMC 3945 has the ability to record the voltage and was used in this assessment to identify stations with a ground or near ground condition.

At a few stations, voltages between zero and 90 volts were recorded between one phase conductor and ground. The other phases showed greater than 380 volts to ground. This is an indication that the neutral point has shifted and a ground condition will eventually occur, as depicted in Figure 12-3, Abnormal Phase-to-Ground Voltage Recording at Station F-10.

Figure 12-3 – Abnormal Phase-to-Ground Voltage Recording at Station F-10



At several stations, the standby generator was observed to be solidly grounded. The mixing of ungrounded and grounded electrical systems is not compatible. A ground fault in the ungrounded system is temporarily acceptable; however, it is totally unacceptable in a grounded system because it would cause the unit or protective device to trip.

To reconfigure the transformer bank from a grounded or ungrounded DELTA to a grounded WYE configuration will require the replacement of the individual transformers (three per bank), replacement of the service conductors from three to four, replacement of the meter sockets (8 jaws with 7 jaws for self-contained meters and 8 jaws with 13 jaws for those with current transformer metering) and replacement of the service entrance conductors to three with ground at those stations where the ground conductor is not installed. Also, design engineered drawings for each station must be submitted to GPA Engineering and the Guam Department of Public Works.

High resistance grounding offers some of the benefits of an ungrounded system in limiting transient over voltages. This method applies a resistor between the transformer neutral and the ground to limit the ground fault current. The transformer connection is still a WYE configuration. If one of the phase legs goes to ground, the system would continue to operate, with the resistor limiting the current and voltage. Maintenance personnel need to know that this condition exists in order to take corrective action as ground in an ungrounded system. The second ground fault will be a damaging phase-to-phase short circuit. For this reason, this connection method is not recommended.

Another method of grounding in an ungrounded system is the use of a zigzag transformer, which allows the flow of zero sequence or ground fault currents. This type of transformer will provide a ground reference to limit the phase-to-ground voltage and be solidly or resistance grounded.

Figure 12-1 is an example of a grounded center tap DELTA transformer connection. Note that the center phase leg (V2) is 409 volts to ground while the other two legs (V1 and V3) are approximately 240 volts to ground. The single higher voltage phase to ground places stress on that phase conductor as well as requiring operators to be aware of the higher phase leg. This is not a recommended method of grounding the electrical system.

The condition depicted in Figure 12-2 occurs when one of the phase legs (V1) has gone to a ground condition. The other two phases (V2 and V3) are measured at 462 and 469 volts to ground, respectively. The insulation system is stressed to ground at phases V2 and V3. When either of these two phases goes to ground, a phase-to-phase short circuit will exist and a high fault current will flow. In many cases, this condition would continue undetected and is an electrical code violation.

At several stations, this condition was evident where holes were blown in the metallic raceway or gutter. At Station EX-11, the ground conductor carried the resistance-limited current causing the insulation to melt between the motor ground and the service ground.

Although the phase-to-phase voltage to the motor may be close to normal, corrective repair action must be implemented because failure is imminent.

The condition depicted in Figure 12-3, occurs when one of the phase legs is connected to ground through the system impedance (capacitance reactance and resistance). This is an early indication that a part of the insulation has broken down in Phase V1. The voltages on Phases V2 and V3 are 391 volts and 458 volts, respectively.

The figure also exhibits a non-sinusoidal waveform, denoting the presence of harmonics caused by the systems inductive and capacitive reactance. With conditions favorable for a resonant condition, higher than nominal voltages can exist between one or two phases to ground. This will be exhibited only in the phase-to-ground voltage readings. These voltage readings were taken at the motor starter, with the unknown being the voltage at the motor termination. The motor would continue to operate with this condition undetected until a failure occurs.

12.4.2 Voltage and Current Unbalance Issues

Two methods for computing voltage or current unbalance are recognized, either ANSI (American National Standards Institute) or IEEE.

In the ANSI Method, the percentage of phase unbalance (voltage or current) is calculated by taking a percentage of the greatest variance from the average and dividing it by the average, then multiplying it by 100%, as described below:

% Unbalance = [Maximum Deviation from Average/Average] x 100%

ANSI Phase Unbalance Computation Method

The IEEE method of computing the voltage unbalance uses the following equation to compute the percentage of current unbalance, substitute current (I) for voltage (V).

% Voltage Unbalance = [3 x (Vmax – Vmin) / (Va+Vb+Vc)] x 100%

IEEE Unbalance Computation Method

Regardless of which method is used for the computation, the higher the unbalance the greater the effect on the electrical equipment. Since the more common method is that shown in the ANSI Method, it is used in this report.

This percentage is an indication of the voltage quantity or current variation and greatly affects the operation of an electrical motor. The effect of voltage on the current drawn by the motor is explained using symmetrical component theory. In a simple explanation, a normal electric motor is driven by positive sequence currents that rotate in a direction to produce mechanical work. The current unbalance creates a degree of negative sequence currents that flow in the opposite direction with the same frequency or counter to producing productive work. The net effect is a force that is driving the motor in the opposite direction and simulates a braking action that is counterproductive, much like driving a car with one foot on the accelerator and the other on the brake.

The motor must overcome this braking effect and therefore operates with reduced efficiency and greater heat generation, both of which seriously decrease motor insulation life. This loss often leads to premature motor failure by overloading the driven pump motor, especially deep well submersible or hermetically sealed motors such as those used in refrigerator compressors. This is due primarily a result of the compact nature of the motor, in which little space is allocated for heat dissipation (approximately 50 hp in an 8-inch diameter frame, for example).

To overcome this effect in the past, the response has been to oversize the motor to account for the pumping and the dragging effect, resulting in a greater operating cost to obtain the desired water.

The losses within the motor equate to approximately two times the square of the voltage unbalance. For example, a voltage unbalance of 2 percent is equal to a loss of approximately 8 percent; for 3 percent, there is an 18% loss. This percentage loss is a substantial energy cost compared with the water or end product delivered.

Table 12-2, Station Y-15 Readings lists the spot voltage and current readings, as well as corresponding unbalances and power and power factor (PF) readings.

Table 12-2 – Station Y-15 Readings

Reading Date	Voltage			Unbalance (%)	Current (amps)			Unbalance (%)	KW	PF
06/30/04	462.0	476.0	474.0	1.8%	142.5	165.1	178.5	12.1%	109.3	.82
08/25/04	475.4	484.1	486.2	1.3%	155.2	131.8	177.7	14.7%	105.5	.82
10/22/04	462.6	471.6	475.6	1.5%	156.3	155.1	176.5	8.5%	109.4	.83
01/12/05	476.2	479.4	477.9	0.3%	167.2	166.7	161.3	2.2%	111.5	.82

The 125-hp deep well submersible motor at Station Y-15 failed in July and December of 2004. The August recording was taken after the motor was replaced in July. The October recording was with the same motor and the January recording was made after the motor was replaced again. No recordings were taken when a new motor was installed in December and the motor failed once more after only a couple of weeks in operation.

The 125-hp motor has the following nameplate rating: Full load current of 167 amps at 460 volts and 109 kilowatts (kW). With the service factor of 1.15, the maximum current is 188 amps and 125 kW.

Based on the data collected, most of the challenges with voltage unbalances were observed in the areas affecting the F, D and M series of water wells, although each location need be addressed on a case-by-case basis. Although these were spot readings and different manufacturers' motors were used, they are representative of what was occurring at the station at the time the readings were taken. Recordings were not made during the evening and readings were not taken over a three-day or longer period.

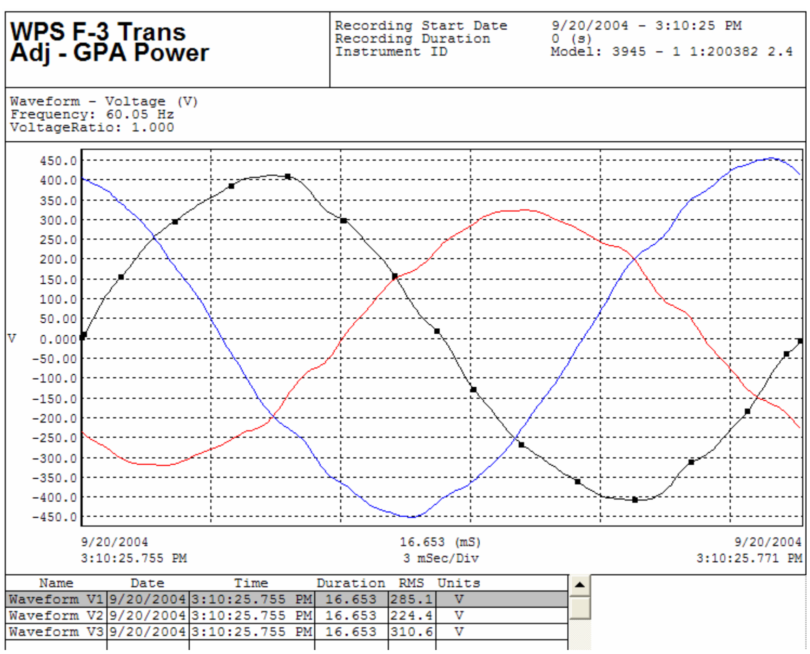
A primary factor is well fields that also serve blocks of residential single-phase loads. Other factors to consider are the distance from the substation transformer to the load, any primary voltage capacitor bank installations, other commercial and industrial loads and voltage regulation equipment.

At the treatment plants, the service voltage was noted to be stable while being powered through pad-mounted transformers. Equipment such as blowers and pumps, which operate continuously, are affected, however. Most of the wastewater pump stations located in the same area as the water wells are less affected, despite the unbalance voltage, because the pumps are only operated for a short period (usually less than 10 minutes), which is insufficient time for heat generation to occur.

Correcting this voltage unbalance will yield one of the highest returns to GWA and GPA by improving water pumping efficiency and increasing electrical revenue.

Figure 12-4, Phase-to-Ground Voltage Recording – Station F-3 presents typical voltage readings to ground, showing that the neutral point of the ungrounded DELTA has shifted from a normal 277 volts to ground to 224 volts to ground. This condition should be periodically monitored to determine whether a shift in voltage to ground continues, which indicates continued failure of the insulation level on the phase with the lower voltage, as shown in Figure 12-3. Note also the slight presence of voltage harmonics on the sinusoidal fundamental waveform.

Figure 12-4 – Phase-to-Ground Voltage Recording – Station F-3



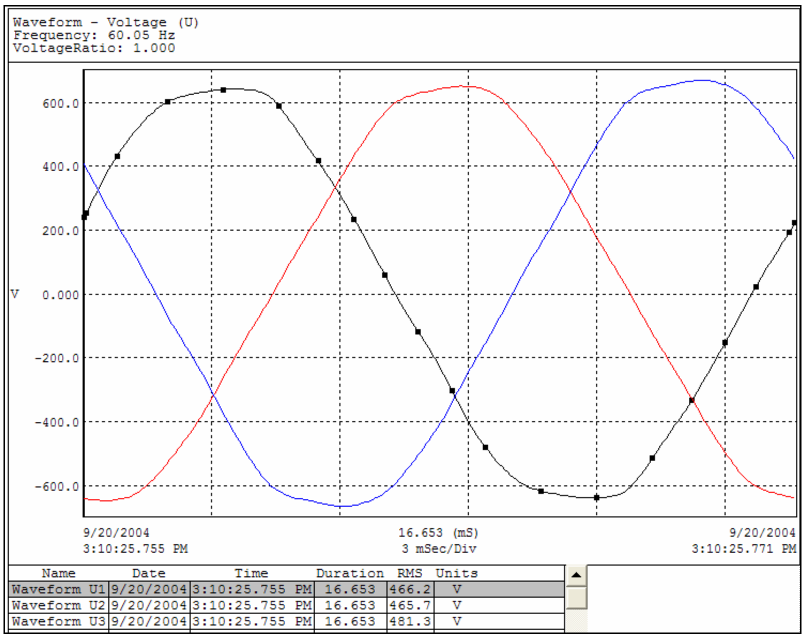
A balanced, solidly grounded system would not exhibit a drastic variation of this condition. Rather, when the voltages to ground differ, it is an indication of a phase-to-phase voltage unbalance.

Figure 12-5, Phase-to-Phase Voltage Recording – Station F-3 indicates the voltage provided to the motor. The voltage unbalance is calculated as follows:

Average Voltage = (466 + 465 +481) / 3 = 470.6 Volts

% Voltage Unbalance = [(481 – 470.6) / 470.6] x 100% = 2.2%

Figure 12-5 – Phase-to-Phase Voltage Recording – Station F-3



In this case, despite their unbalance voltage variation, the voltages provided to the motor exhibit a sinusoidal waveform. This is an example where the use of the AEMC Model 3945 Power Quality Analyzer can display the voltage waveform and value between the phase and electrical neutral point as well as compute the voltage unbalance.

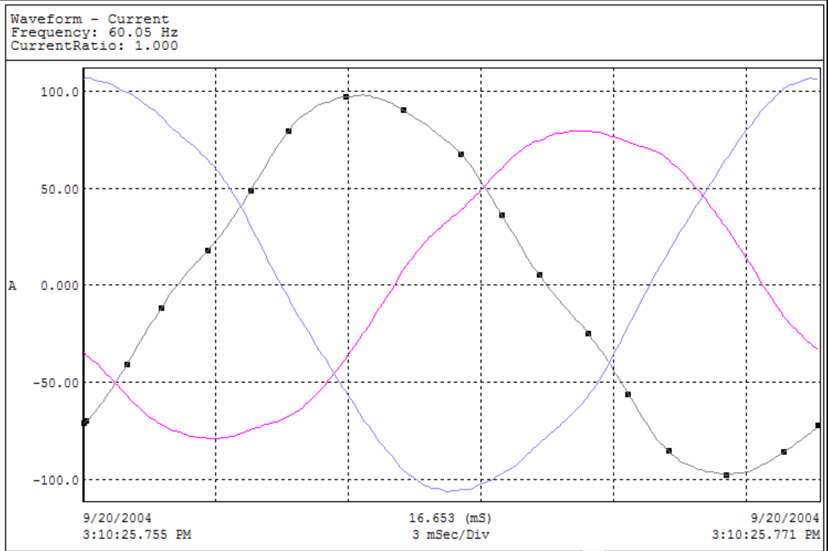
Figure 12-6, Phase Current Recording – Station F-3 shows the corresponding current during the same period as the voltage recording in Figure 12-4 (phase to ground) and Figure 12-5 (phase to phase).

The current unbalance is computed as follows:

Average Current = (68 + 57 + 75) / 3 = 66.6 Amps

% Current Unbalance = [(66.6 – 57) / 66.6] x 100% = 14.4%

Figure 12-6 – Phase Current Recording – Station F-3

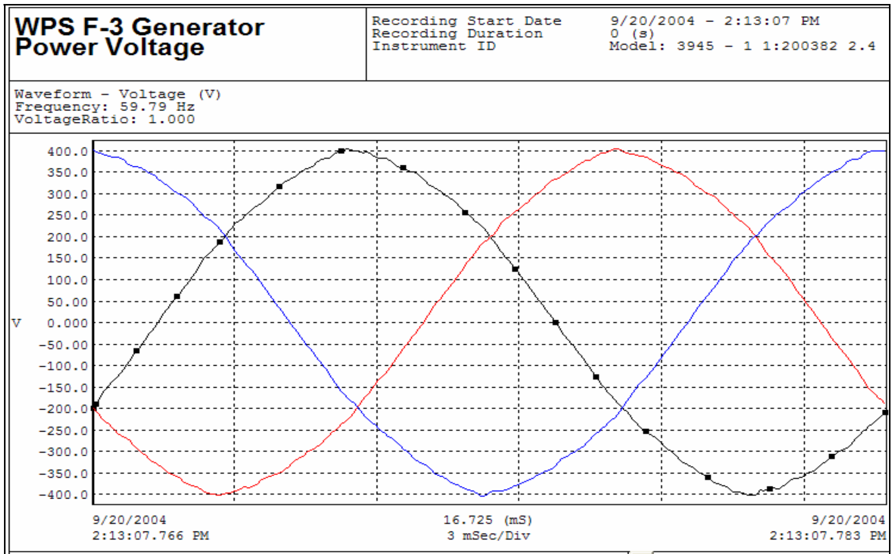


Name	Date	Time	Duration	RMS	Units
Waveform I1	9/20/2004	3:10:25.755 PM	16.653	67.99	A
Waveform I2	9/20/2004	3:10:25.755 PM	16.653	56.82	A
Waveform I3	9/20/2004	3:10:25.755 PM	16.653	74.99	A

Despite the variables dealing with motor and installation practices, this figure depicts the relationship between voltage and current, wherein a voltage unbalance affects a consequent current unbalance.

As shown in Figure 12-7, Phase-to-Ground Voltage on Generator Power – Station F-3, Station F-3 was operated on the emergency generator with the voltage was recorded. This recording should also be compared with Figure 12-4 (on GPA power). Note also the balanced voltage to ground resulting from a grounded WYE connection within the generator.

Figure 12-7 – Phase-to-Ground Voltage on Generator Power – Station F-3

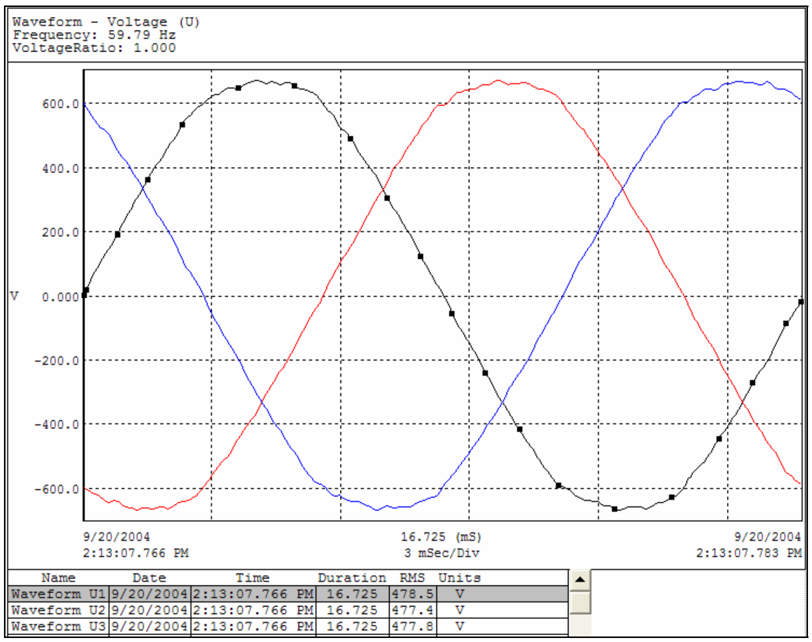


Name	Date	Time	Duration	RMS	Units
Waveform V1	9/20/2004	2:13:07.766 PM	16.725	276.2	V
Waveform V2	9/20/2004	2:13:07.766 PM	16.725	275.9	V
Waveform V3	9/20/2004	2:13:07.766 PM	16.725	275.5	V

The corresponding voltage unbalance is calculated to be 0.1 percent. This is an indication that the voltage unbalance (2.2 percent on GPA power and 0.1 percent on generator power) is largely attributable to the transformer voltage unbalance and service conductors. This is a good test example and method to determine the source of the voltage unbalance at any of the water and wastewater pump stations.

Figure 12-8, Phase-to-Phase Voltage on Generator Power – Station F-3 shows the corresponding phase-to-phase voltage that the motor would be provided when operating on the emergency generator. The corresponding voltage unbalance is also 0.1 percent.

Figure 12-8 – Phase-to-Phase Voltage on Generator Power – Station F-3

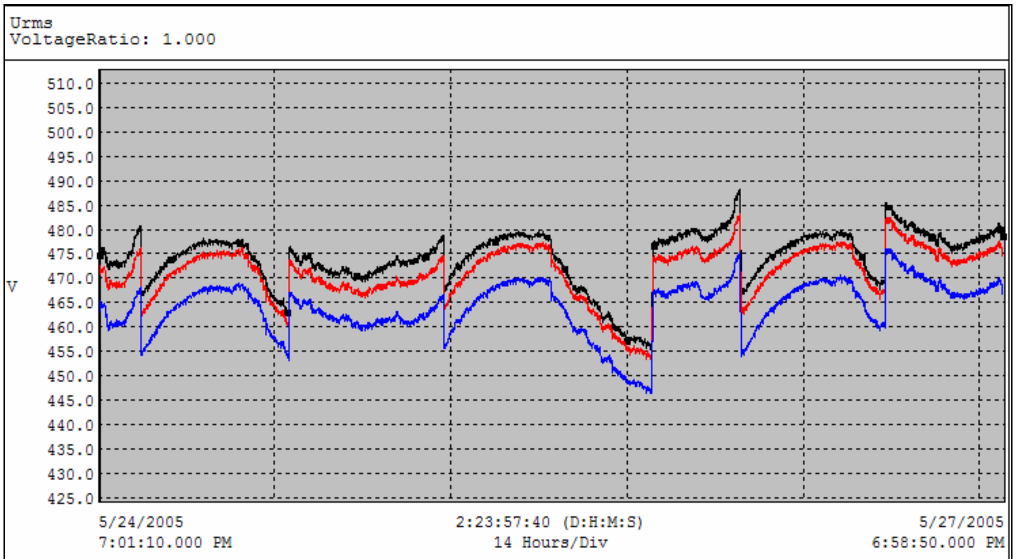


Although the phase current was not measured because the pump was not operated during this test, a balanced voltage will be the first step in determining the source of the unbalance condition.

Again, this is a test procedure to be implemented to determine the condition of the motor or equipment on GPA and generator power. See the Implementation Section 12.7.1 for a detail of this procedure.

A three-day recording made at Station M-20A in May 2005 provided valuable information about the operation of the GPA electrical system. As shown in Figure 12-9, Three-Day Trend Recording – Station M-20A – May 24-27, 2005, the voltage recording showed a wide swing (490 volts to 445 volts). This variation was investigated by GPA and found to be caused by manual changes to the tap changer at the substation transformer. In August 2005, information was received that the tap changer, which normally operates automatically to adjust the voltage, was being repaired.

Figure 12-9 – Three-Day Trend Recording – Station M-20A – May 24-27, 2005



Name	Date	Time	Avg	Min	Max	Units
Urms Line1	5/24/2005	7:01:10.000 PM	474.1	455.3	488.2	V
Urms Line2	5/24/2005	7:01:10.000 PM	471.1	453.2	483.0	V
Urms Line3	5/24/2005	7:01:10.000 PM	464.0	446.3	475.9	V

This is an example where multiple day recordings (minimum of three days) at the station were used to identify and aid in solving a challenge that has affected the M-20A well. The settings of the protective voltage and current sensing relays need to be studied, coordinated and adjusted.

12.4.3 Electrical Meter Failures

At several locations, the meter socket failed. This failure was caused primarily by a flashover between the phase-to-phase conductors or phase-to-ground conductors.

Despite having a “drip loop” for the exterior of the conductor, this failure is attributed to incidences where water has entered the meter socket through the interior of the conductors themselves. In those cases where the terminal connections at the transformer were installed using a downward method, water has been allowed to enter into the center of the conductor winding and drip into the breaker or meter terminations.

In instances where self-contained meters are used, the corrosion will appear at the metering terminals, as shown in Figure 12-10, Electrical Meter Failure. In locations where current transformers are used, the water accumulates at the main breakers instead, as shown in Figure 12-11, Breaker Corrosion. This process may take several years before any amount of water develops.

GPA Standard Practices already incorporate the installation of transformer wiring terminations in such a way that the conductors are looped upward and therefore new installations incorporate this change. All currently installed pole transformer service conductors that are not looped, are subject to this condition and need to be re-terminated.

Figure 12-10 – Electrical Meter Failure

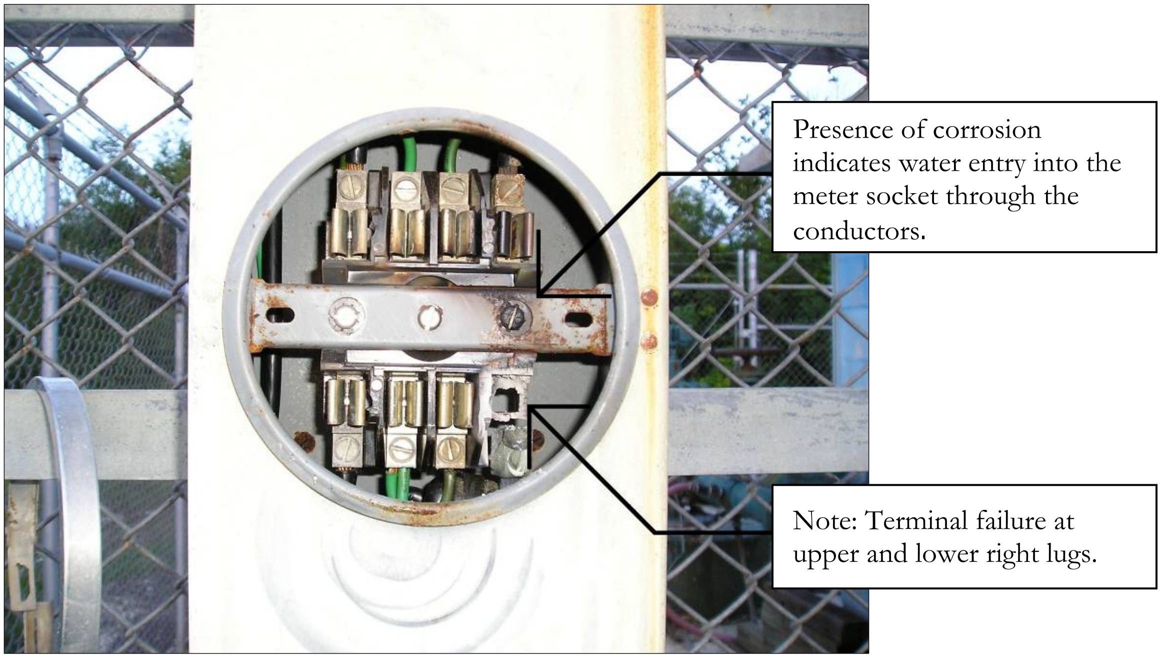


Figure 12-11 – Breaker Corrosion

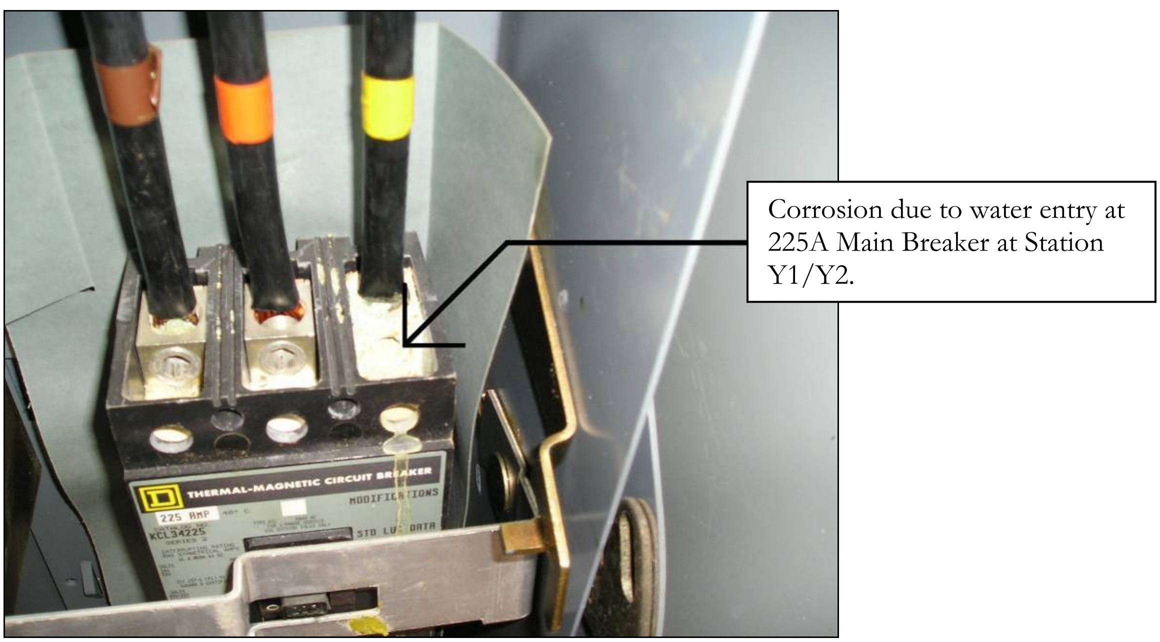
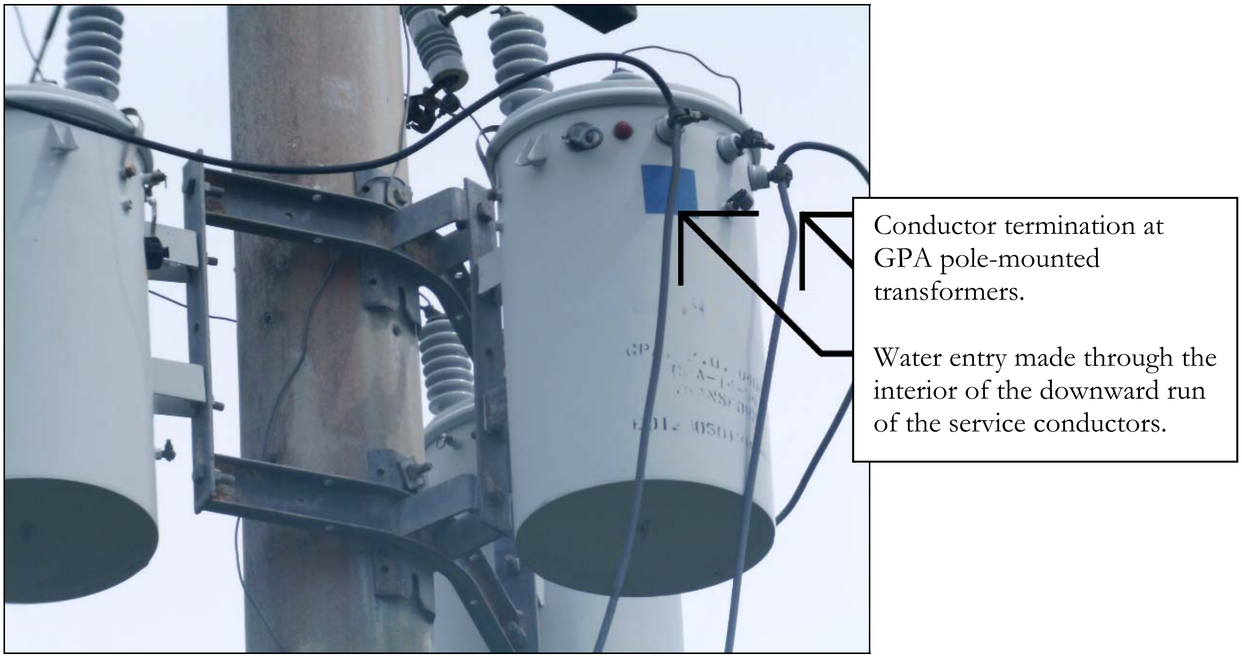


Figure 12-12, Pole Conductor Termination shows how the termination at the power transformer with the downward vertical conductors which act a conduit for water entry.

Figure 12-12 – Pole Conductor Termination



Conductors using XHHW or RHW insulation are better equipped to minimize this water entry situation.

12.4.4 Motor Overload Protection

Most of the motor starter, overload protection units in use are the Cutler Hammer BA Series. This unit provides a Class 20 characteristic response (i.e., relates to the responsiveness of the relay to an overload condition).

In terms of water wells, the Franklin Electric Company (which supplies the majority of the deep well pumps) recommends the use of a Class 10 overload protection response.

In an operating condition and due largely to voltage unbalances, one current leg is generally higher than the other two. If this relay is adjusted for the lower relay current setting, nuisance tripping will occur. If this relay is adjusted for the higher leg current, which sometimes may be at or near the maximum reading, protection is compromised.

A feature of the Class 20 relay is the ability to accept individual overload relay heaters (which supposedly simulate the condition within the motor or equipment it is protecting) and adjust for the unbalanced current. This is not an ideal solution, but it can provide a temporary compromise regarding nuisance tripping. The Class 10 relay has only one adjustment, making the protection scheme harder to adjust.

To improve the protection of the deep well motors, of which GWA has the greatest inventory of installed motors, the manufacturer (Franklin Electric) offers a motor protector capable of sensing the temperature of the motor windings in its Sub-Monitor Premium unit. The sensor in the motor has the ability to communicate with the motor protector through the power wiring and hence to shut down the motor in an abnormal condition.

In addition, the installation of a voltage unbalance relay interlocked with the control circuitry and located within the automatic transfer switch at the water pump station is recommended. This relay will allow for the automatic starting of the generator and a transfer to generator power until the voltage situation is corrected. This control arrangement will continue to provide the desired product (water) as opposed to using a voltage unbalance relay at the pump, which would cause the pump to shut down (i.e., for lack of water).

The transfer switches need to be locked so that this sensing relay cannot be tampered with and only authorized personnel can make any changes.

12.4.5 Phase Monitors or Motor Protectors

Several stations were equipped with phase monitors to check the effects of voltage loss, reversal and over- or under-voltage conditions. Voltage monitors are available on the market that verifies the unbalanced current as well. These monitors are generally connected at the line side of the motor starter (Timemark C263 and Linebacker 600 Series) or across the motor starter (Linebacker 800 Series). Electronic sensor relays are generally not well suited for monitoring unbalanced voltage or current, but they offer a faster response to single-phase conditions than the motor overload relay does.

Limiting the effectiveness of sensitive monitoring equipment is valid tripping that cause a valid shutdown of the pump or motor. These cause nuisance callouts, after which the settings are either changed or the relay bypassed, rendering the control ineffective.

These phase monitoring units are not well suited to deep well motor challenges and should be re-applied with other motor locations within the system.

Protectors for submersible motors, such as the Sub-Monitor unit manufactured by Franklin Electric or the Motor Saver unit manufactured by Symcom for motor applications, provide a higher level of protection in a single package, including various classes of overload current trip, voltage and current unbalances, current range limits and motor internal thermal protection. These motor protectors are the premier choice for these applications.

12.4.6 Reduced Voltage Motor Starting

Various methods of motor starting are available, with the most common being “across the line” or application of full voltage to the motor. This method results in the highest current flow (approximately six times more than full load current) and torque and likewise the highest internal electrical and external mechanical stress. The high inrush currents also cause voltage sags on the utility lines that can, in turn, affect other electronic equipment.

Reducing the voltage decreases the current and resultant mechanical stress. The most common method of reducing the voltage is the use of an adjustable autotransformer. This method is a timed one-voltage step (usually 65% or 80%) to cause motor rotation before full power is applied. Other motor starting methods, such as part winding and WYE-DELTA, are available but were not observed during this assessment.

Another common method for the larger horsepower motors is the use of electronically reduced voltage motor starting. These starters have the ability to provide fairly smooth starting and stopping by allowing the voltage applied to be ramped over time. They are particularly beneficial where high mechanical torque is applied on a frequent basis, such as level-controlled devices. The ramping will also reduce the hydraulic stress on the water and wastewater system piping and check valves.

The use of reduced voltage motor starting is also a requirement by GPA to minimize voltage sags on its system. With the advent of expanded use of electronic devices, power quality issues are utility hot buttons.

These starters require a contactor to bypass the reduced voltage electronics when the motor is operating at rated speed. In a few models, the contactor can start the motor in an across-the-line mode as a backup. This is not a recommended mode of operation; however, it is essential for continued operation. The use of this starter type was observed at the Fujita and Route 16 WWPSs. Both are good applications.

At several stations, the autotransformer had burned and a full voltage starter was installed. The burning of the autotransformer was likely the cause of overheating, resulting from a failed starter timing relay. In the deep well applications, the long motor lead wire acts as a resistor to automatically limit the current and voltage to the pump.

12.4.7 Motor Oversizing

Another practice for providing motor overload protection has been the installation of a pump motor that is larger than that originally designed for the station. As an example, the original design for several stations show 40-hp motors, but 50-hp motors had been installed. This 10-hp increase essentially provides a 25% safety factor to the motor. The effects of unbalanced voltage on the motor make this a viable alternative to reducing motor failures, particularly with the submersible pump motors.

A few drawbacks are, in some cases, that the motor and starter wiring were sized for the smaller pump. This condition has caused termination overheating, leading to motor failure.

Based on the data collected with the power quality analyzer, the electrical loading of the motor was determined. The observation was that motors that were carrying approximately 80% or less of their rated load could handle the voltage unbalances better than those that were carrying a greater amount. The latter condition reflects higher losses and costs of operation.

At a few stations, the recordings showed that the motor was carrying a service factor load of 15% over its rated load. Verification of the pump flow rate and the power consumed provides an indication of the pump efficiency. Motors that operate at their service factor load are in danger of premature failure.

The power quality analyzer equipment is capable of recording the power (real and reactive) required by the motor. Such data are valuable because they are independent of the voltage and current in determining the load on the motor.

12.4.8 Standby Generators

At most stations, a standby generator was installed to provide emergency power during an outage. At most of the water wells, the generators are owned and maintained by GPA, whereas at most of the wastewater stations the generators are owned and maintained by GWA. Most of the GPA generators are manufactured by Generac or Caterpillar. The GWA units include Kohler, Onan, Generac and Caterpillar, among others.

Most of the GWA units observed at the water and wastewater pump stations did not have a battery installed and therefore could not operate during a power outage.

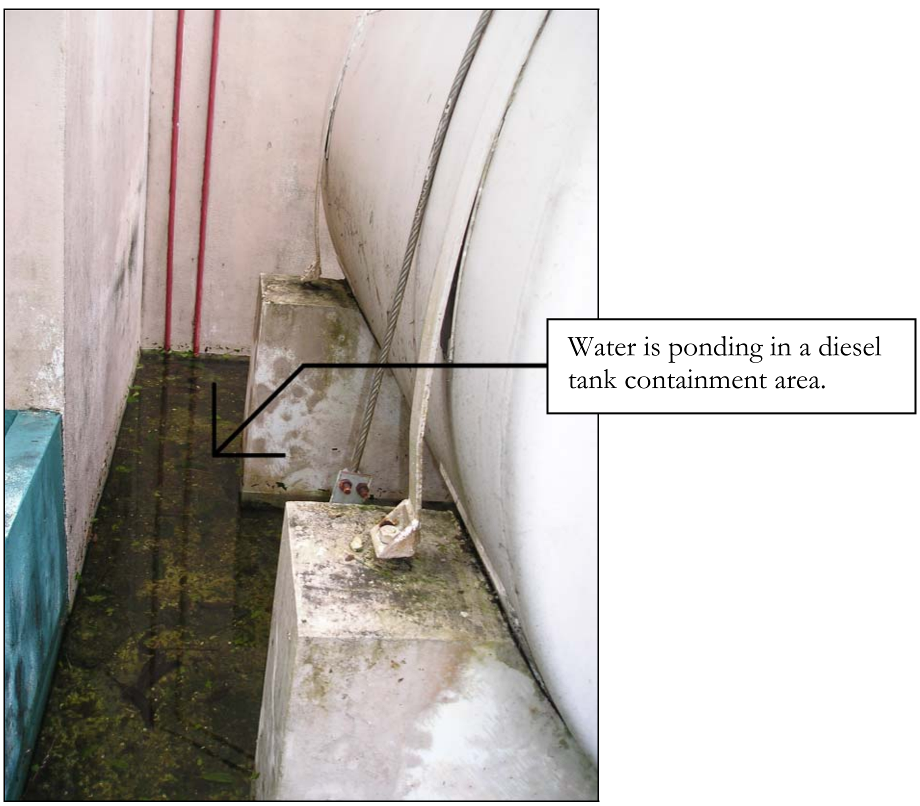
At Station Y-1, the generator cover was removed and the wiring traced so that the neutral of the generator was grounded to the system ground. At other stations, the generator internal connections appeared to be solidly grounded based on the voltage to ground measurements observed. The generator voltage is 480Y/277 volts, grounded, while the service voltage is 480 volts, ungrounded. This difference in connection will cause a conflict when operating the grounded generator on a ungrounded system with a ground fault condition present. Either the protective device will trip or further damage will occur to the grounded device location.

12.4.9 Diesel Fuel Line Building Wall Penetration

At several water pump stations, water entry into the electrical and generator rooms is evident, occurring primarily during and after a rainstorm.

At stations where the diesel fuel tank containment area is adjacent and attached to the generator room and the fuel line is located below the containment wall, water enters through the diesel line penetration, as shown in Figure 12-13, Diesel Fuel Line Penetration – Station A-3. The resulting condition creates an electrical safety hazard to all personnel entering and working in the wet floor environment.

Figure 12-13 – Diesel Fuel Line Penetration – Station A-3



The water in the diesel fuel trench and storage containment area also expedites the corrosion of the fuel lines to the generator, as shown in Figure 12-14, Generator Room Fuel Line Penetration – Station A-3. This could affect the proper operation of the generator in the future or allow water to enter the fuel system.

Figure 12-14 – Generator Room Fuel Line Penetration – Station A-3

To reduce the effects of this condition, the containment area drain pipe was in an open position, allowing the water to drain. This practice, however, would also allow a diesel spill to drain in the same way, which is not desirable.

Additionally, at a few stations water entry was noted in the electrical room. The apparent cause was the electrical control raceways being located at a higher elevation and in the vicinity of the wellhead. These raceways return to the electrical control cabinets and the conduit covers had been removed.

Stations where the diesel fuel tank was located within the building and in its own containment area were not affected.

12.4.10 Coordination with GPA

The identification and analysis of electrical challenges at GWA facilities require a working cooperative relationship with GPA in order to analyze and resolve future electrical failure occurrences. The installation of power quality instruments to record data will assist in the analysis and processing of information that can be shared with interested parties.

12.4.11 Voltage at Motor

The final voltage at the motor (at the bottom of the well) is a result of all the voltage drops from the transformer, service conductors, feeders, circuit breakers and motor starters. The motors are rated at a nominal 460 volts and therefore a voltage of 480 volts at the motor starter should ensure that the required voltage is delivered at the motor.

The sizing of the motor cable conductors must follow the manufacturers' recommendation, which is specified in the service manual for the particular motor size installed.

What may be a more meaningful measure is the power supplied to the motor, recorded in kilowatts (kW). A percentage would be allocated to the voltage drop in the motor conductors while the majority would be that of the motor itself. The power readings would be fairly constant despite variations in the voltage and current and are a better measure of performance and comparison. The minimum delivery voltage at the motor starter should not be less than 470 volts, however.

The motor loading was used as a secondary consideration in assessing failure susceptibility. In cases where the actual load on the motor was measured at approximately 80% of the nameplate service factor rating, a higher degree of unbalance current could be tolerated. Those stations where the motor loading was in the motor service factor range have a higher probability of failure and in fact several failed during the assessment period. See the pump station summary in Appendix 1K.

Most of the deep well motors had a service factor of 1.15 or a 15% safety cushion. Those motors that failed were operating in the safety cushion area, which allows very little room for the motor to handle voltage variations.

The pump operating hydraulics is an important factor in pump loading and should be considered when determining the actual motor load.

12.4.12 Pump Station Grounding

The electrical grounding system at the station is essential for protection and safety of personnel, as well as in the application of transient voltage surge suppressors (TVSS). Both grounding and bonding of the electrical components, beginning with the utility equipment to the well pump, are necessary and must be addressed.

As recently observed at most stations, the utility transformer grounding system is separate from that of the well. The station building grounding system is also separate from the well, except for an equipment grounding conductor that is installed along with the motor phase conductors. At several locations, the grounding electrode conductor (between the equipment and the ground rod or grounding means) was cut or removed, apparently a victim of theft.

In the Northern District area, the ground resistance registered relatively high ohmic readings (in the 130-ohm range). This result was likely due to the type of soil conditions present at the time of the reading, although the ground was moist after a heavy rain.

It is recommended that the ground system be multiple-grounded at several locations, such as the pole, handholes, meter socket, service entrance, main breaker, station steel and well-head.

The well shaft is likely the best ground at the deep water wells because it is has the best conductive path to the groundwater. Although using the well shaft as the ground for the site would be advantageous, grounding and bonding conductors would have to be installed between the service conductors, building electrical and the well.

12.4.13 Lightning and Surge Arresters

Lightning and power surges can cause tremendous damage to electrical and electronic equipment. Protection from these effects must be considered if additional electronic equipment is to be incorporated into the facilities.

Lightning strikes directly affect the power system and must be dissipated in a safe manner to minimize any hazard to personnel or property. Most of the GPA transformer power poles use lightning arresters to dissipate the energy to ground. At several stations, however, lightning arresters were missing or "blown", as shown in Figure 12-15, Missing Lightning Arrester. Missing or high impedance ground connections are a detriment to effective surge suppression.

Besides lightning strikes and depending on the rating of the lightning arrester, failures caused by line-to-ground faults on a high impedance grounding system (ground at the substation) could place higher than normal stress on the arrester itself, thereby leading to its early failure. The high impedance ground is attributable to the distance of the fault from the substation.

This was evident at Station HG-2A after one of the transformers faulted to ground. When one of the fuses was replaced, the new fuse took about a second or two to blow, which is an indication of the limited fault current available on the 13.8-kV system at this station. The likely cause is the high impedance of the return path. This issue, however, is one that needs to be investigated by GPA.

Figure 12-15 – Missing Lightning Arrester

The lightning arresters are the first line of defense in protecting the station. Most of the stations surveyed were not equipped with surge suppression devices to act as a second line of protection.

Several of the motor failures could be attributed to electrical power surges, as they seemed to occur during or after an electrical lightning storm.

The installation of a tiered TVSS system at all facilities and GWA offices is recommended. A tiered system is one that would provide several levels of protection, as follows:

1. Service entrance equipment – Larger unit at the main breaker
2. At the protected device, critical motors and devices and motors over 50 hp in size
3. All electronic or computer devices

The TVSS units should be equipped with replaceable modules of standardized sizes. The location and type of electrical system to which the unit is to be installed (WYE or DELTA) must be identified. The installation of an effective ground at each site is essential for proper operation of these protection devices.

12.4.14 Power Factor Correction Capacitors

Power factor is basically the ratio of the electrical systems' ability and capability to produce effective work (horsepower over distance and time). Induction motors require reactive power to operate. This reactive power, however, does not produce work. It does increase the apparent power (kilovolt-amperes or kVA) that the electrical system must provide, whether this power is from the generator, synchronous condenser, or power factor correction bank. This increased apparent power increases system losses and voltage drop.

Power factor capacitors serve as a source of capacitive reactive power or volt-amp reactive (VARs) to counteract the motor's source of inductive reactive VARs. By supplying a portion of the VARs at the well or pump station, the capacitor help improve the voltage by reducing the effective impedance that cause a reduction of current that yield a reduction in the voltage drop.

The power factor at the various facilities was measured from a low-to-high 80% range, with the ideal being 100%. Installing power factor correction capacitors would help to raise and stabilize the voltage at the facility and provide a degree of surge suppression within the capability of the capacitor bank. A projected design target in the 95% range is desirable.

Most of the GWA facilities are under the 200-kW demand range and are billed at the GPA Schedule K – Small Government Service rate structure (see Exhibit 12A) and do not benefit from an improvement by power factor correction. This power factor correction benefit will yield an improvement by stabilizing the station operating voltage.

The large demand facilities (greater than 200 kW) would benefit by this improvement when greater than 87% by offering a 0.15 percent credit per point reduction. For example, for a facility that currently has an 80% power factor, its 0.45 percent penalty would change to a 1.2 percent credit when the average power factor is improved to 95%. This would equate as a monthly credit of 1.65 percent of the energy portion of the electrical bill or approximately 19.8% of the average monthly bill, on an annual basis.

The installation of power factor capacitors is advisable for all stations greater than 50 hp in rating and are connected to operate with the driven piece of equipment.

12.4.15 GWA Personnel Work and Maintenance Practices

The proficiency level of the GWA electrical staff varies, based primarily on prior work experience and training. Staff skill development is largely dependent on outside vendor or contractor technical expertise, on-the-job training and individual effort. Trouble-shooting expertise and capability also vary.

A structured predictive or preventive maintenance program was not observed to be in use. Much of the observed daily routine was dedicated to troubleshooting and repair or replacement of failed equipment. At times, repairs were made with nonconforming but available parts (i.e., several panels were supplied with International Electrotechnical Commission (IEC) parts instead of National Electrical Manufacturers Association (NEMA) standard parts). An effort to standardize inventoried replacement parts was also observed. Cannibalization of parts from one station to keep another station operational was also observed. Various instances of creativity were observed, many of which were driven by necessity or lack of funding.

12.5 Electrical Assessment

Table 12-3 shows details pertaining to the Wastewater Pump Station Assessment; similarly, Table 12-4 summarizes the Water Pump Station Assessment.

Table 12-3 – Wastewater Pump Station Assessment Summary

Station Name	Utility Service Info	Building Service Info	Standby Generator	Pri. Pump Motor Ctrl	Sec. Pump Motor Ctrl	Chlorination Motor Starter	Pump Controls	Building Electrical	Assess ment Value
AGANA MAIN	0.41	0.1	0.225	0.48	0.48	0	0.27	0.06	2.0
ALUPANG COVE	0.39	0.225	0.325	0.6	0.6	0	0.25	0.06	2.5
ASAN	0.38	0.175	0.475	0.6	0.6	0	0.22	0.03	2.5
BARRIGADA	0.4	0.225	0.6	0.6	0.6	0	0.3	0.09	2.8
BAYSIDE	0.38	0.15	0	0.4	0	0	0.14	0.03	1.1
CABRAS	0.38	0.15	0	0.6	0.6	0	0.24	0.09	2.1
COMMERCIAL PORT	0.57	0.225	0.45	0.64	0.64	0	0.2	0.09	2.8
DAIRY ROAD	0.47	0.15	0.2	0.48	0.48	0	0.2	0.06	2.0
DBL. TROUBLE	0.59	0.225	0.6	0.52	0.52	0	0.27	0.045	2.8
FEMA 96	0.57	0.225	0.15	0.6	0.6	0	0.17	0.03	2.3
FUJITA	0.57	0.175	0.35	0.52	0.52	0	0.2	0.09	2.4
HAFI ADAI	0.39	0.05	0.075	0.4	0.48	0	0.2	0.03	1.6
HARMON	0.27	0	0.175	0.52	0.52	0	0.25	0.06	1.8
HUEGON #5	0.54	0.225	0.45	0.68	0.68	0	0.3	0.105	3.0
INARAJAN MAIN	0.4	0.2	0.425	0.52	0.32	0	0.2	0.06	2.1
LATTE PLANTATION	0.43	0.225	0.475	0.36	0.36	0	0.2	0.09	2.1
MACHANANAO	0.45	0.15	0.25	0.32	0.32	0.02	0.2	0.03	1.7
MACHECHE	0.38	0.2	0.525	0.32	0.32	0	0.2	0.06	2.0
MAITE	0.38	0.225	0.6	0.32	0.36	0.02	0.2	0.06	2.2
MAMAJANAO	0.37	0.15	0.475	0.4	0.4	0	0.27	0.045	2.1
MANGILAO	0.42	0.225	0.575	0.48	0.36	0.02	0.27	0.075	2.4
OLD CHAOT	0.38	0.1	0.325	0.52	0.52	0	0.25	0.03	2.1
NEW CHAOT	0.59	0.3	0.6	0.72	0.72	0.04	0.3	0.09	3.4
ORDOT	0.43	0.225	0.6	0.64	0.64	0	0.25	0.09	2.9

Table 12-3 – Wastewater Pump Station Assessment Summary (continued)

Station Name	Utility Service Info	Building Service Info	Standby Generator	Pri. Pump Motor Ctrl	Sec. Pump Motor Ctrl	Chlorination Motor Starter	Pump Controls	Building Electrical	Assess ment Value
PACIFIC LATTE	0.41	0.225	0.45	0.6	0.6	0	0.22	0.06	2.6
PAGO DOUBLE SHAFT	0.37	0.175	0.025	0.6	0.6	0	0.22	0.06	2.1
PASEO DE ORO	0.28	0.225	0.475	0.52	0.44	0	0.27	0.06	2.3
PITI	0.38	0.225	0.6	0.6	0.6	0	0.27	0.09	2.8
PS-12	0	0.225	0.6	0.6	0.32	0	0.17	0.06	2.0
PS-15	0.38	0	0	0	0	0	0	0	0.4
PS-17	0.4	0.225	0.5	0.56	0.52	0	0.25	0.06	2.5
ROUTE 16	0.57	0.175	0.225	0.64	0.64	0.02	0.25	0.06	2.6
SANTA ANA	0.02	0.15	0.225	0.4	0.48	0	0.25	0.06	1.6
SANTA CRUZ #3	0.54	0.225	0.45	0.68	0.68	0	0.22	0.105	2.9
SINAJANA	0.57	0.225	0.6	0.6	0.6	0	0.27	0.09	3.0
SOUTHERN LINK	0.57	0.225	0.475	0.56	0.56	0	0.2	0.06	2.7
TAI MANGILAO	0.38	0.225	0.6	0.6	0.6	0	0.22	0.045	2.7
TALOFOFO	0.43	0.175	0.325	0.6	0.6	0.04	0.22	0.03	2.4
YIGO	0.43	0.225	0.575	0.44	0.44	0	0.25	0.06	2.4
YPAOPAO	0.55	0.225	0.225	0.6	0.6	0	0.22	0.015	2.4

Table 12-4 – Water Pump Station Assessment Summary

Station Name	Utility Service Information	Building Service Information	Standby Generator	Pump Motor Starter	Chlorination Motor Starter	Pump Instrumentation	Building Electrical	Assessment Value
A-01	0.45	0.45	0.575	0.7	0.13	0.05	0.12	2.5
A-02	0.5	0.45	0.6	0.75	0	0.065	0.15	2.5
A-03	0.5	0.45	0.575	0.75	0.13	0.05	0.15	2.6
A-05	0.475	0.45	0.575	0.5	0.12	0.085	0.1	2.3
A-06	0.5	0.45	0.575	0.55	0.12	0.1	0.1	2.4
A-08	0.5	0.45	0.6	0.55	0.12	0.13	0.15	2.5
A-09	0.5	0.45	0.575	0.65	0.14	0	0.13	2.4
A-10	0.475	0.45	0.275	0.7	0.14	0.05	0.1	2.2
A-14	0.5	0.45	0.6	0.75	0.14	0.02	0.1	2.6
A-15	0.475	0.45	0.575	0.8	0.14	0	0.15	2.6
A-18	0.55	0.45	0.6	0.75	0.14	0	0.15	2.6
A-21	0.425	0.4	0.6	0.75	0.14	0	0.12	2.4
A-28	0.5	0.35	0.6	0.5	0.12	0.055	0.15	2.3
A-29	0.55	0.45	0.6	0.7	0	0.07	0.15	2.5
A-30	0.5	0.35	0.425	0.6	0.12	0.035	0	2.0
A-31	0.55	0.45	0.6	0.55	0.12	0.03	0.12	2.4
AG-2A	0.5	0.45	0.475	0.8	0	0.07	0.13	2.4
D1-D2	0.5	0.45	0.6	0.75	0.14	0.03	0.15	2.6
D-04	0.5	0.4	0.575	0.75	0.14	0	0.15	2.5
D-07	0.5	0.45	0.6	0.75	0	0	0.15	2.5
D-08	0.5	0.45	0.575	0.55	0	0.015	0.15	2.2
D-10	0.45	0.45	0.6	0.55	0	0.015	0.15	2.2
D-11	0.275	0.45	0.6	0.55	0.12	0.015	0.15	2.2
D-12	0.5	0.45	0.6	0.55	0	0.03	0.15	2.3
D-13	0.45	0.45	0.6	0.65	0.14	0.015	0.15	2.5
D-14	0.5	0.35	0.6	0.5	0.07	0.035	0.15	2.2
D-15	0.5	0.45	0.6	0.55	0.07	0	0.15	2.3
D-16	0.475	0.45	0.6	0.75	0.14	0.05	0.15	2.6
D-19	0.35	0.45	0.575	0.75	0.03	0.08	0.15	2.4
D-20	0.4	0.45	0.575	0.5	0	0.05	0.13	2.1
D-21	0.5	0.45	0.6	0.75	0.14	0.035	0.13	2.6
D-22	0.5	0.45	0.35	0.6	0.14	0.02	0.15	2.2
EX-11	0.35	0.45	0.575	0.55	0.12	0.05	0.15	2.2
F-02	0.5	0.45	0.575	0.75	0.14	0.03	0.15	2.6
F-03	0.45	0.45	0.6	0.7	0	0.06	0.15	2.4
F-06	0.5	0.45	0.6	0.75	0.14	0.05	0.15	2.6
F-07	0.5	0.45	0.6	0.7	0	0.065	0.15	2.5
F-09	0.45	0.45	0.6	0.55	0	0.05	0.15	2.3
F-10	0.5	0.45	0.5	0.55	0.12	0.1	0.15	2.4
F-11	0.5	0.45	0.6	0.75	0.14	0.08	0	2.5
F-12	0.5	0.45	0.6	0.75	0.13	0.055	0.15	2.6
F-13	0.5	0.45	0.275	0.6	0.14	0.1	0.15	2.2
F-15	0.5	0.25	0.525	0.7	0.14	0.1	0.12	2.3

Table 12-4 – Water Pump Station Assessment Summary (continued)

Station Name	Utility Service Information	Building Service Information	Standby Generator	Pump Motor Starter	Chlorination Motor Starter	Pump Instrumentation	Building Electrical	Assessment Value
F-16	0.45	0.4	0.275	0.6	0.06	0.035	0.12	1.9
F-17	0.5	0.45	0.325	0.65	0.13	0.08	0.12	2.3
F-18	0.5	0.35	0.425	0.6	0.14	0.05	0.12	2.2
HCG2	0.45	0.5	0	0.55	0.08	0.05	0.24	1.9
M-02	0.475	0.45	0.6	0.7	0	0.05	0.15	2.4
M-03	0.2	0.45	0.575	0.75	0	0.045	0.15	2.2
M-06	0.425	0.45	0.6	0.55	0.07	0.05	0.15	2.3
M-09	0.475	0.45	0.5	0.75	0.14	0.06	0.15	2.5
M-15	0.6	0.45	0.55	0.6	0.12	0.085	0.1	2.5
M-17-B	0.525	0.6	0.575	0.75	0.12	0.05	0.12	2.7
M-18	0.55	0.45	0.45	0.6	0.12	0.1	0.1	2.4
M-20-A	0.55	0.45	0.5	0.7	0.12	0.055	0.12	2.5
M-23	0.6	0.45	0.5	0.75	0.11	0.085	0.1	2.6
Y-01	0.5	0.3	0.55	0.45	0.12	0.06	0.15	2.1
Y-02	0.5	0.3	0.55	0.55	0	0.045	0.15	2.1
Y-05	0.425	0.45	0.575	0.55	0.12	0.085	0.15	2.4
Y-06	0.5	0.45	0.6	0.55	0.12	0.08	0.15	2.5
Y-09	0.425	0.45	0.575	0.6	0.12	0.07	0.1	2.3
Y-10	0.45	0.45	0.45	0.7	0.11	0.1	0.1	2.4
Y-15	0.675	0.6	0.5	0.65	0.14	0.1	0.15	2.8
Y-17	0.65	0.3	0.6	0.75	0	0.1	0.15	2.6
Y-21-A	0.45	0.35	0.45	0.55	0.11	0.1	0.15	2.2
Y-23	0.6	0.45	0.35	0.7	0.14	0.1	0.15	2.5

The final assessment value, as shown in the far right column of each table, is the weighted average of each of the different areas, as outlined in Table 12-1. The detailed assessment sheets are located in Appendix 1K.

Stations that scored below 2.0 were generally found to be either missing important items or certain portions of the station were non-functioning.

The detailed assessment sheets in Appendix 1K also include comments on the findings (see the farthest right column, following the comment guide).

12.6 Implementation Approaches Based on Field Observations

The following implementation ideas are based on the observations and findings of the overall electrical assessment.

12.6.1 Partnering Effort with GPA and GWA Quality Circle Groups

In the effort to accumulate better electrical data, assistance in the analysis of information and corresponding corrective action is essential. Based on these data and site observations, development of a station punch list for corrective action and identification of an individual point of contact are recommended. The development of an internal GWA Quality Circle Group, comprising electrical, engineering and operations personnel from water and wastewater operations to identify areas requiring attention, is also recommended. This group would also attend meetings with GPA personnel, preferably on a monthly basis, to update corrective actions, evaluate work progress, review current electrical challenges and anticipate future tasks. It would be advantageous for members of this focus group to attend electrical conferences to share and expand both individual and group skill levels in solving electrical challenges. Suggestions for training and conferences are covered later in Section 12.6.6.

The cooperative effort at Station Y-15 in January 2005, following a recent motor failure, is an example of the potential advantages of this approach. Basically, the motor failure was the fourth one in 2004. The transformer bank, lightning arresters and service conductors, as well as the motor starter and well motor conductors, were replaced. The voltage was balanced to less than 0.3 percent with the resulting motor current unbalance reduction to approximately 2.2 percent. Participants in this incident included personnel from GWA, GPA, Earthtech and various vendors.

12.6.2 Relocation of the Diesel Fuel Lines

The issue of water entering the generator building and electrical room creates a safety hazard to all personnel within the facility. It is imperative that all metallic equipment be bonded and grounded as dangerous voltages could be present and the presence of water increases the hazardous condition. Water also accelerates the corrosion of the steel piping and equipment. This condition is mostly evident at buildings where the diesel fuel tank is located on the exterior wall that is adjacent or attached to the generator building.

GPA is currently working on relocating the diesel fuel lines at several stations. At those stations containing GWA generators, the diesel fuel tank and lines were installed within the building and are not an issue.

Installation of a chemical valve that would allow water, but not diesel oil, to flow through is recommended. The valve would solidify if any oil product were to come in contact with the chemical cartridge. The cartridge would then be replaced and sent to the landfill. This item is commercially available. Its cost is not known as of this report date.

The relocation of diesel fuel lines is a priority safety issue requiring immediate attention. The cost is estimated at $1,000 for each station that requires this work. In meetings with GPA, the lines to be relocated by the GPA generator crew would be discussed to get their recommendations.

12.6.3 Power Quality

Several items relating to the quality of power are discussed below.

12.6.3.1 Phase Voltage Unbalance

The percentage phase voltage unbalance is the greatest contributor to deep well motor shutdowns and/or failure. The line voltages have a direct correlation with the phase current and motor losses. The motor manufacturer (Franklin Electric) and NEMA recommend no greater than a 1 percent voltage unbalance for operation of motors. As discussed earlier, this condition is most evident in the operation of the deep well submersible motors and less of a factor with those motors that are ambient air cooled. To overcome this condition, larger horsepower motors were installed by GWA that also resulted in a higher unit operating cost.

Based on the data recordings, not all water well stations experienced this voltage unbalance condition. Most evident are stations that affect the F, D and M water wells. It is recommended that those stations with a voltage unbalance exceeding 1.5 percent receive priority attention, adjusting the transformer bank with the goal of less than one percent unbalance. The re-working of the service conductor termination at the transformer would be performed at the same time, as well as any corrections relating to grounding and lightning arresters.

The test for confirming unbalance is to record the voltage and current while the motor is operating on utility power, then again while it is operating on the emergency generator. If a large change (say, 10 to 2 percent) occurs in the measured current, it is attributed to voltage unbalance. If the change is small, then the effect is due to a problem with the motor or its electrical system within the station.

Each deep well motor, either existing or newly installed, should be checked for its minimum unbalance condition by raking the motor leads. This technique must be performed each time the basic motor conditions change.

Installation of a voltage relay specifically manufactured for monitoring voltage unbalance is also recommended. This unit should be adjustable and have a 1- to 5-percent range, with a maximum 20-second time delay. Units in the 1- to 10-percent range would not provide the refinement needed. These relays would monitor the utility voltage unbalance only and they are more sensitive than those normally provided by automatic transfer switch manufacturers. The Time Mark Corporation Model C200 3-Phase Voltage Unbalance Monitor, modified for a 1- to 5-percent adjustment range, is recommended. The installation of these voltage relays is a high priority item.

The estimated labor and minor material cost for each station is $600. Each relay is estimated to cost between $250 and $300. A budget of $1,000 per station is estimated.

12.6.3.2 Voltage Variation

Large variations in the service voltage need to be further recorded over a three-day period. The security of leaving the test instruments at the site for the duration of this period is an issue because the cabinets often cannot be locked. A way to pursue further recording of voltage data is essential in order to better analyze the power at a given station. The voltage differences between day and night could be significant and could affect pump performance. The data would also be valuable to GPA in improving its service.

The recordings taken at Station M-20A in May 2005 reinforce the need for such data collection. The voltage swing was significant and visually showed the switching effects of the GPA substation load tap changer on the voltage of the GPA system.

A further recommendation is that recordings using the AEMC 3945 Power Quality Analyzer be continued at all priority stations. This information, along with the recordings made over the past year, will become the basis for future reference and analysis.

12.6.3.3 Transient and Surge Protection

Missing or ungrounded surge arresters at the utility pole were observed at several sites. These arresters form the first line of defense against power surges and lightning strikes. They are primarily intended to limit the surge to the transformer bank. Depending on the transformer Breakdown Insulation Level, a large portion of the voltage surge would be transferred to the secondary windings. This would appear on the line-to-line voltage as well as the capacitive coupling to ground.

It is imperative that these protection devices be intact and functional. Few or no secondary surge protection units were observed during the electrical assessment. A few of the installed devices were not operational.

It is recommended that secondary TVSS protection be installed at the building service and connected to an established grounding system. Consideration must be given to the type of transformer connection (WYE or DELTA and grounded or ungrounded) and to the type used for service applications before ordering. The majority of the stations are of the DELTA, ungrounded configuration.

The estimated cost for transient surge suppression at the building service is estimated at $2,500 per unit.

12.6.3.4 Electrical Grounding System

The establishment of a low resistance grounding system to dissipate power and lightning surges is vital to the protection system. Bonding or connecting all metal parts to minimize any potential differences between equipment is also critical for safety. Consequently, grounding and bonding are interrelated for safe operation.

Use of the well shaft casing at the water wells as the primary ground at each facility is highly recommended. All other items are to be connected to a copper ground bus (located in the station building), with a heavy conductor connecting or bonding these two.

The connection to the well casing would be thermally welded and treated to prevent corrosion. A resistance reading of less than 5 ohms to ground using the fall of potential method of measurement is recommended.

12.6.3.5 Transformer Connection and Ground Monitoring

The method by which electrical service is received is primarily 480 volts, three phase, three wire, ungrounded. The transformer bank is connected in a DELTA configuration. Together with the improvements in station grounding and application of surge protection devices, it is recommended that all stations be converted to 480Y/277 volts, three phase, three wire, solidly grounded.

The solidly grounded system will limit occurrences of transient voltages due to capacitive coupling, as well as the voltage on the insulation, to ground. The TVSS units for a grounded system need to be applied.

As a precaution when converting the present ungrounded DELTA transformer bank to a grounded WYE, personnel should check for the presence of an existing ground or shift in neutral point to ground. This condition must be cleared and corrected prior to energizing the WYE system; failure to do so will produce ground faults to flow.

Ground detectors, which are needed to detect when one of the electrical phases is grounded, are required by the National Electrical Code (Article 250.21). The AEMC 3945 Power Analyzer is capable of recording and displaying the phase-to-ground voltage condition and can be used to identify its location.

12.6.4 Electrical Metering Challenges

The method of service conductor transformer termination has led to incidences of meter socket failures. A flashover between the phase-to-phase terminals and phase-to-ground terminals (systems where a second ground has occurred on the system) are due to water infiltration. This would be evident by an inspection of the meter sockets where a self-contained meter is installed and at the line side of the station main breaker where current transformer (CT) metering is used.

It is recommended that GPA meter personnel, along with a GWA electrician, inspect all the meter sockets for signs of oxidation on the meter or the breaker terminals, as well as for corrosion (rusting) within the meter socket. Those stations exhibiting signs of corrosion should be scheduled for conductor and meter replacement.

The wiring method at the transformer must be corrected so that more water does not enter the conductors. These conductors need to be identified and replaced when the transformer bank is scheduled for replacement.

The use of type XHHW insulated wire is recommended for the service conductors. The appropriate conductor sizes are listed in Table 12-5.

Table 12-5 – Conductor Sizing

Station Breaker	Station Horsepower	Conductor Size	Meter Socket Rating
100 A	50 hp or less	#1 AWG	200 A – Self Contained
225 A	75 and 100 hp	#4/0 AWG	200 A – Self Contained
400 A	125 hp to 200 hp	#500 MCM	CT Rated

Note: AWG = American wire gauge; MCM = thousand circular mils.

The recommended minimum size conductor for any electrical service is 100A, #1 AWG. A minimum, 200A self-contained meter sockets are recommended for all installations.

12.6.5 GWA Operational and Maintenance Issues

The following issues relate to GWA operational and maintenance issues and practices.

12.6.5.1 Motor Protection

Motor Overload Protection – The motor overload relay protective device most evident in the water and wastewater equipment is a Cutler Hammer Class 20 unit. This application is acceptable for most aboveground applications; however, it is not recommended for the submersible deep well pumps, primarily because of its response time. A Class 10 unit, which has a faster response time, is recommended.

GWA has initiated the installation of motor protector relays with adjustable overload classifications. These units, using the trade name of "Motor Saver" or "Sub-Monitor," and provide voltage and current unbalance protection in addition to phase reversal, loss of phase, high and low voltage, under and over current trips and ground fault settings, as well as time delays and re-start functions. The Sub-Monitor unit does not deal with current transformers while the Motor Saver unit does. This is somewhat of a disadvantage because the correct current transformer must be procured and wound into the unit and the multiplier applied.

The Sub-Monitor unit also has the ability to detect the temperature abnormality in the deep well motor. This is a distinct advantage as the conditions at 400 feet below the earth's surface will likely be different than at the surface. When used with the "Premium" version of this unit, a three-year warranty is extended to the motor. In essence, this implies that the motor would experience nuisance tripping and be shut down to protect itself. As a result, the need to correct the voltage unbalance and install the unbalance voltage monitor at the auto transfer switch is a very high priority.

In all cases, as improved motor protection devices are installed, the incidence of shutdowns will increase. Tampering with the settings is not the recommended solution, but such action may be necessary to maintain operation.

It is recommended that the Premium model of the Sub-Monitor be installed for all submersible deep well motors. The auto transfer switches would also be equipped with a voltage unbalance relay to turn on the standby generator and operate it as long as the voltage is unbalanced. This model will provide the best overall protection for the continued water production of the well motor.

The unit cost for the procurement and installation of the Premium Sub-Monitor model is estimated to range from $1,000 to $1,500.

Motor Oversizing – Installation of a larger motor than that which is required for the station is another means to account for the voltage unbalance condition. This approach may have been indirectly carried out in the process of keeping the deep well motors from prematurely failing, but the result has been decreased efficiency of operation.

The pump hydraulics for each of the deep wells should be reviewed to determine the proper sizing of the pump and motor. Additionally, these motors should be oversized to one size larger, with the objective of operating the motor at its rated load and not at its service factor load.

The motor conductor size, motor starter size and overload protection must be coordinated and rechecked with the new parameters.

Phase Monitor or Motor Protectors – Phase monitors and motor protectors, such as the Timemark, Linebacker and Motor Saver Series, are currently installed at many sites. They help to minimize motor failures caused by loss or reversal of phase voltage, as well as high or low voltage conditions. Such equipment should be applied at all motors critical to system operation. However, except for the Motor Saver, they have limitations when used with the deep well motors.

For the deep well motors, the Franklin Electric Premium Sub-Monitor, or its direct equivalent, is recommended because it will serve all of the functions of the phase monitors described above as well as monitor the phase unbalance currents and voltage and the motor temperature, all in a single package. The Timemark and Linebacker phase monitors could be removed and re-used at the water booster pump stations and treatment plants. The remaining units are to be used at the wastewater pumping and treatment facilities, so that all motors are protected. Use of the Linebacker 800 Series or the Motor Saver or the Franklin Electric Standard Sub-Monitor, or their equivalent, is recommended for the critical operating motors, such as the blowers and wastewater pumps.

Reduced Voltage Motor Starting – Electronic reduced voltage motor starters, although more complex than those that use an autotransformer, offer protection from loss of phase, phase reversal, high and low voltage and other conditions, similar to the phase monitors currently in use. Further protection is offered because the electronic circuitry will sense motors that are shorted and will shut down or prevent their operation. These devices also have the ability to limit and ramp up the starting current for a softer start, thereby placing less mechanical stress on the pump. They are particularly beneficial for the larger horsepower motors with a high frequency of operation.

The installation of electronic reduced voltage starters with a full horsepower rated bypass contactor and on and off ramping functions is recommended for all motors greater than 100 hp in size. This recommendation is intended to limit the mechanical stress on the motor. If these units are to be installed in an existing motor control cabinet, the enclosure must be protected from the environment and preferably enclosed by gaskets. Additionally, the raceways entering the enclosure should be sealed with duct-seal to prevent the entry of insects and vermin.

Electronic reduced voltage starters are recommended for motors greater than 30 hp having a high frequency of operation (six starts or more per hour). These starters should also be equipped with a full rated horsepower bypass contactor and adjustable ramping functions.

The budgetary costs for these recommended starters will vary, based on motor size, but generally the difference between autotransformer and electronic starters is comparable for units greater than 100 hp.

12.6.5.2 Power Factor Correction

The installation of power factor correction capacitors to operate with the equipment will help to stabilize the voltage at the station. The projected design power factor target of 95% is desirable.

The installation of power factor capacitors is recommended for all stations motors that are 50 hp or greater in size. The capacitors would be approximately 10 to 15 Kilo-VAR (KVAR) in size, depending on the loading and station power factor.

Power factor correction capacitors that are oil-filled are preferred to those having an electrolyte. Also, units that have smaller individual capacitors in parallel are recommended because an individual failed capacitor could be replaced as opposed to replacing the entire unit. Oil capacitors have a higher breakdown rating and are selfhealing. The capacitor unit should also have indicator lamps to show the status of any blown fuses (indicating a capacitor unit failure) while in operation.

In a normal motor starter, the capacitor should be connected to the load side of the motor starter and ahead of the overload protection device. In this way, the capacitor will not influence the protective device setting. In electronic motor starters, the power factor capacitors need be connected to a separate contactor and be engaged after the motor has reached its rated speed. A contact closure from the starter is used to signal the closure of this auxiliary contactor. The sizing of the contactor should be in accordance with the capacitor rating. Installing the capacitor at the load side of an electronic starter will damage the starter when the electronics are in operation.

The budgetary cost for this item is based on the size of the capacitor bank and is approximately in the $20 per KVAR range.

12.6.5.3 Pump Operation during Commissioning

During the commissioning period after a motor is installed, the pump is operated in a bypass condition to purge the well until the laboratory test results clear the well to be put online. At times, the bypass valve is operated in a fully open position. Because the wellhead pressure is at its minimum, the motor has been observed to carry a full or greater than full load. During the electrical assessment period, a new motor failed while operating in the bypass mode.

It is recommended that the hydraulic design for each well be reviewed to match the system requirements. Until such time, the pump current load should be checked while in the bypass mode and personnel should be instructed to limit the manual valve position.

12.6.5.4 GPA Operation and Maintenance of Generators

Based on observations made during the electrical assessment, the stations operated and maintained by GPA maintenance technicians were generally better secured and operated during the intermittent tests that were conducted. Most of the GWA generators were without batteries, except prior to and after a storm. During non-storm periods, the batteries were removed for storage.

Several wastewater pump stations did not have an operational generator. The generator was either missing or damaged, or it lacked a battery. These generators are planned to be replaced shortly.

It is recommended that the operation and maintenance of all generators (including those at office facilities) be performed by the GPA generator personnel. This practice will entail standardizing units for spare parts and personnel training.

At some time in the future, GWA could re-acquire the generator operation and maintenance responsibilities, if desired.

12.6.5.5 Aluminum Service Conductor Usage

In areas where a high degree of conductor theft has occurred, aluminum service conductors could be considered as a deterrent. The proper treatment of and use of anti-oxidizing compounds on the terminations is essential to maintaining service without incident.

Aluminum conductors are less flexible to handle and therefore the bending radius must be observed when installing raceways.

12.6.5.6 Predictive and Preventative Maintenance Program

Periodic Maintenance and Testing – Current operations and maintenance practices indicate that GWA's electrical maintenance program requires a shift from reactive to proactive in order to enhance the utility's reliability and protect the capital investment made by its ratepayers. With proper test equipment and training, GWA staff can implement a preventive and predictive maintenance program.

The initial source of information for such a program is the equipment manufacturers' instruction and operating manuals. The information for each equipment item is usually provided in hard copy format. In many instances, digital electronic files are available on compact disc (CD), digital video disc (DVD), or on-line from the manufacturer. Several manufacturers offer online and factory training courses, as well as on-site courses based on the number of attendees.

Another source of information is NFPA 70B – Recommended Practice for Electrical Equipment Maintenance (latest edition) produced by the National Fire Protection Association. This publication offers a wealth of information about electrical equipment maintenance principles and practices, prepared maintenance forms and testing procedures and methodologies. Adoption of these practices will enhance the electrical maintenance program.

Other information sources are factory-trained field or sales engineers visiting the island. These sources are usually offered through the sales representatives and cover a range of sales- and maintenance-oriented sessions. Taking advantage of these opportunities when they arise is essential, particularly in those areas where a large investment has been made, such as well motors and pumps, bearings and lubrication, motor controls and electronic devices.

In testing and maintaining equipment, the use of proper personal safety equipment is essential to limit injury from electrical arc flashes. In compliance with Occupational Safety and Health Administration standards, adoption of NFPA 70E – Electrical Safety in the Workplace is recommended as a guideline for worker safety.

Motor Controls – The motor starters and ancillary controls are vital to the operation of the driven equipment. Where the frequency of equipment operation is high (six or more starts per hour), the motor starter contact and terminations need to be checked for wear on a regular basis, e.g., quarterly. Worn contacts must be replaced with new or reconditioned contacts.

A few cases were observed where moisture had entered the contactor, creating a loud humming sound. Cleaning and lubricating the armature iron will minimize this condition.

12.6.5.7 Test Equipment and Tools

In addition to training, good test equipment and tools are essential to conducting an effective preventive and predictive maintenance program.

The following equipment is recommended, as a minimum:

- Voltmeter (True RMS - Root Mean Square)
- Ammeter (True RMS)
- Megohmmeter (1,000 volts)
- Power quality analyzer
- Infrared imager
- Vibration analyzer (also capable of balancing)
- Motor analyzer and tester (surge comparison tester)
- Alignment tools (laser and gauge type)
- Safety insulated hand tools, gloves and personal protective clothing

Electrical training on special procedures can be provided by the equipment manufacturer.

Basic Test Instruments – The basic test instruments of electrical and maintenance personnel in the trade are the volt-ohm-meter or multi-meter. These units read the basic units of voltage, current and resistance. Only True RMS meters should be used for these purposes because inaccuracies could develop when measurement of nonlinear waveforms is.

Several multi-meters have the ability to read other parameters, such as frequency, capacitance and inductance and diode junction voltages and so forth.

Megohmmeter – Testing the insulation value for motors (460 volts) requires the use of an instrument capable of producing voltages that are comparable. A battery-operated megohmmeter that can produce incremental direct current (DC) voltages up to 1,000 volts is recommended. Care must be exercised when applying this voltage to electronic devices.

Besides insulation resistance (value taken at one minute of testing), a Polarization Index (the ratio of the value taken at ten minutes divided by the value at one minutes) and Dielectric Absorption (the value at three minutes divided by the value at one minute) provide an indication of the insulation quality.

A multi-meter will not generate sufficient voltage to accurately measure DC resistance in a motor and therefore should not be used for this purpose.

Power Quality Analyzer – A power quality analyzer, capable of recording waveforms and events such as surges, sags and transients is required to display, in graphic form, the invisible parameters of electricity. This tool must be capable of recording sample rates in the 256-times-per-cycle range to be effective and also be able to download the information for further analysis.

GWA has procured the AEMC Model 3945 Power Quality Analyzer to fulfill this requirement and has begun obtaining valuable information regarding the power quality at the various stations.

Infrared Imaging of the Electrical Equipment – Infrared imaging techniques have been used very effectively to predict and assess the condition of equipment, often long before any failure occurs. However, the equipment to be evaluated must in operation during the assessment period.

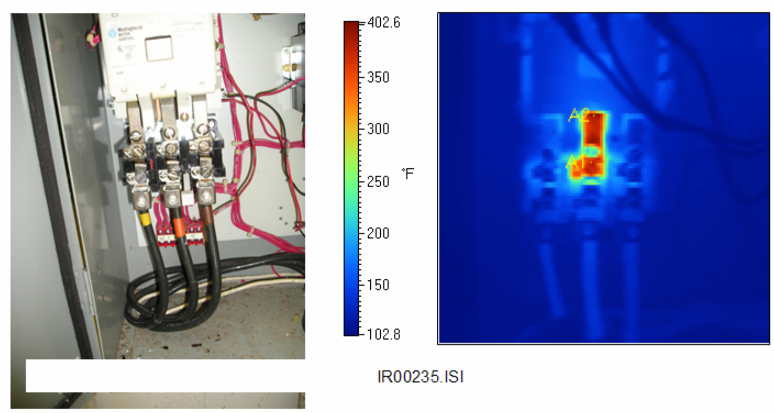
During this electrical assessment, several potential electrical failures were averted through the use of infrared imaging as nuisance tripping of overload relays due to overheated terminations were noted. Frequently, after an overload relay was tripped, the connection had cooled down by the time maintenance personnel arrived so the unit relay was reset and equipment operated again, only to trip once more. Consequently, in some cases the overload heater size was increased to keep the unit operational and compromising the protected equipment.

The cost of infrared imaging instruments has been dropping with improvements in technology. The Flir E Model series is recommended because of its real-time display and its light weight. A unit with 160 x 120 resolutions would be sufficient for most electrical work.

Working in conjunction with a GPA infrared team is another method to conserve resources and provide cross training of personnel. Figure 12-16, Infrared Image of Motor Starter depicts an overheated overload condition at the Station Y-5 motor.

Figure 12-16 – Infrared Image of Motor Starter

Y-5 Motor OL



Info:

Image Path	C:\PROGRAM FILES\INFRARED SOLUTIONS\SNAPVIEW 2.1\GUAM IR IMAGES\IR00235.ISI
Image Date/Time	Monday, August 30, 2004 8:53:36 PM
Report Date/Time	Wednesday, October 13, 2004 12:37:47 PM
Temp Unit	Fahrenheit
User	GWA
Location	WPS Y-5
Target	Motor Starter Overload Relay

Data:

Label	Emissivity	Background	Average	Std Dev	Max	Min
A1	0.95	76.96	380.87	0.00	380.9	380.9

Vibration Analyzer – Bearing failures account for more than 50% of motor and equipment failures. Delving into the mechanical world where frequencies are greater than those sensed by human touch is an early predictor, such as the impact of ball bearings within their race or the condition of the impeller blades in a pump or fan. In addition, vibration analysis assists in diagnosing and correcting challenges with misalignment, unbalance, equipment mounting and resonance. Such items as broken motor rotor bars, in a squirrel-case induction motor, can also be detected.

The current equipment uses Fast Fourier Transforms (FFT) technology to break the raw accelerometer readings into their respective frequency components.

The test instrument must be capable of performing field balancing as well as checking alignment practices, where laser alignment is not used. It is a good practice that all motors except the deep well motors, operating at 3,600 rpm synchronous speed, be aligned and checked for vibration after they are installed. The vibration analyzer data will form the basis for the historical record for the particular piece of equipment.

Specific training in the use and operation of this equipment is essential.

Motor Analyzer and Testing – The internal operation of a motor is often difficult to determine without test equipment. Motor analyzers offer both a static and a dynamic view of the motor parameter. Such items as failed stator or rotor bars, stator winding abnormalities (particularly after the stator has been rewound), phase and slot insulation integrity and static rotational indication can be tested.

This tool can assist with a maintenance determination of whether a motor can be re-used after a removal.

Alignment Tools – The mechanical life of equipment is in a direct relationship to the degree of alignment of the motor and the driven device. The time expended in using mechanical gauges for alignment often can be reduced by the use of laser alignment tools having substantially better accuracy. Any alignment settings should be recorded for historical purposes.

Improved bearing life is an additional benefit of correct alignment.

12.6.6 Training

An ongoing training program is a vital part of equipment and personnel maintenance because the background and experience of each individual vary.

The following are areas where further improvements would enhance personnel performance and safety:

- Basic and Advanced Electrical Theory and Circuitry
- Electrical Motor Controls
- Electrical Motors, Transformers, Drives
- Electrical Safety and use of Personal Protective Equipment as per NFPA 70E
- Electrical Code and Practices
- Troubleshooting Control Circuitry
- Basic and Industrial Electronics
- Communications

- Use of Testing Instruments
- Calibration of Equipment
- Root Cause Analysis
- Factory Training on Specific Equipment
- Attendance at Conferences

Personnel attending training sessions are encouraged to train and pass on information to personnel not in attendance. Sharing ideas developed during the training and interacting with other individuals in the field are encouraged. Calculating the economic benefit to the organization as a whole is one means of evaluating the impact.

12.6.7 Variable Frequency Drives

Most variable frequency drives (VFDs) provide double conversion isolation in that the alternating current (AC) utility power is converted to DC and then back to a variable frequency AC using a pulse width-modulated waveform. This conversion methodology essentially isolates the driven motor from the power source.

VFDs are generally equipped with a bypass motor starter (conventional or electronic) that will operate in the event of a failure of the normal variable speed drive. Providing a relatively cool and clean environment is necessary for proper operational life.

The installation or retrofitting costs are higher than installing a conventional motor starting contactor. VFDs are recommended for use in challenging areas where the motors are greater than 75 hp and at wastewater pump stations where a relatively steady flow is beneficial to the process. At water pump stations, this is the alternative of last resort in areas where the power challenges are irresolvable.

The complexity of the electronics requires a higher level of training in troubleshooting and repair. Many electronic technicians are leery of working with 480-volt power circuit devices. Also, these drives are more susceptible to power transients and surges, hence transient surge suppression and grounding are vital for reliable operation.

12.6.8 Grounded versus Ungrounded Electrical Systems

Most of the water and wastewater pump stations are supplied with 480 volts, three phase, by the GPA distribution system. The transformers providing power to these stations are connected in either a DELTA-DELTA or a DELTA-WYE configuration and either in a grounded or ungrounded condition. The predominant configuration is 480 volts, three phase, DELTA, ungrounded.

This configuration has several positive features, such as the operation of the system with one of the phase legs grounded and the ability to operate the station with only two of the three transformers in a bank.

This DELTA connected system has its limitations such as operation of the system with one of its legs grounded yields high fault currents when a second phase leg goes to ground and there is a possibility of generating high, transient, over-voltages to ground when operating in a single ground state.

Another method of operation is in a WYE configuration. Three transformers are necessary for operating when using this connection method. This system lends itself to being intentionally grounded, either solidly or through a line reactance or resistance. The net effect is to limit the voltages to ground for personnel safety as well as limiting equipment damage.

Conversion from a DELTA to a WYE transformer configuration requires an engineering effort and coordination with GPA. The GPA Engineering Department requests design plans, time to order the new transformer and installation of the new bank. The system would also entail revamping and replacing the existing electrical metering and wiring.

It is recommended that all GWA stations (both water and wastewater) be grounded as part of the grounding improvements at each facility. This recommendation is in line with the application of transient voltage surge suppression protection on the system.

12.6.9 Pump Operation and Control

At water pumping facilities, normal operation has been observed to be 24 hours a day, 7 days a week. As the water system is improved (e.g., leaks identified and corrected), the water level at the reservoirs will increase and eventually overflow.

A means of turning off the water well pumps is essential and would be covered by the SCADA system. The provisions for the interfacing of the automatic controls were observed to be installed in most of the stations. At the wastewater pump stations, only local and independent controls were installed, allowing for pump operation based on the wet well level. In several instances, the pump cyclically operated for short intervals of less than a couple of minutes. This causes a tremendous stress on the motor electrical windings, as well as the mechanical system.

These stations should be thoroughly investigated so that more consistent operation is achieved. In several stations, the reduced voltage starters did not engage. These devices must be corrected to protect the life of the motor and other equipment.

12.6.9.1 Wastewater Pump Stations

Based on observations at the wastewater pump stations, a majority of the failures have been mechanical in nature. This outcome is largely attributable to the frequent starting of the pump motors and to misalignment during installation.

The larger pumps at such stations as Southern Link, Route 16 and Mamajanao experience frequent operation. The Fujita station also operated with some frequency; however, continuous pumping was predominant there. Southern Link's 295-hp motor in particular experienced runs of less than five minutes (or a minimum of 10 times per hour). This frequency would yield mechanical problems with the shaft, seals, impeller and electrical winding displacement.

One of the motors removed from the Southern Link station was examined at the motor shop, as shown in Figure 12-17, Mechanical Failure in Submersible Motor. The root cause of the failure was the seal, which allowed wastewater to enter the motor chamber, forming a corrosive gas that affected the rotor and windings. The failure was evident in the motor winding, where a phase-to-phase short flashover occurred.

A high probability of seal failures could be attributable to the alignment method used to install the submersible pump. This is particularly true when mechanical means are used to force the piping to align with the pump or vice versa. The stress caused by this misalignment can cause small changes (in the tens of thousandths of an inch), sufficient to cause a seal to fail.

Figure 12-17 – Mechanical Failure in Submersible Motor

At the Southern Link Station, the moisture alarm and shutdown sensors were not connected or missing.

The moisture and overload sensor is an integral part of the submersible pump protective circuitry. Reports by GWA electricians indicate that these sensors were not re-installed by the motor shop after a rewind. It was also reported these safety devices were not installed by the initial installation contractor. GWA Electrical staff should participate in the inspection and acceptance of any new work involving an outside contractor and in the testing of all protective circuits and controls.

12.6.9.2 Station Flooding (Dry Well)

Four wastewater pump stations were observed to have flooded drywell conditions. This problem was largely due to equipment failure along with a non-functioning or non-existent sump pump.

Although the station could operate using the submersible motor, the other metallic piping, check valves and receptacles are not designed to operate for any length of time in a submerged condition.

Recommended design criteria include the use of standardized submersible pumps, where possible. The moisture and over-temperature sensor installed within the motor is to be connected into the alarm and interlocking circuitry to minimize any possible damage to the motor.

Electrical raceway and devices are not to be installed in the dry well but should be accessible from the first level of the station.

12.6.9.3 Water and Wastewater Treatment Facilities

The majority of the electrical controllers (motor starters, breakers and wiring) at the treatment facilities were observed to be in relatively good condition. The driven equipment in the field (e.g., motors and disconnect switches) was noted to be damaged or in need of replacement.

New blowers were installed at the Baza Gardens Wastewater Facility and the Agat WTP, where the recorded power was less than the nameplate rating.

The inclusion of power factor correction capacitors with new installed equipment is recommended.

12.6.10 Partnering with Local Vendors and Repair Shops

Working with the local vendors and repair shops toward achieving quality repairs and adequate inventory supply excellence is the ultimate goal of a partnering program.

- Rewind motors or equipment to the voltage that the end equipment would be using. For example, a dual voltage motor wound for 230/460 volts, nine leads, would be rewound to 460 volts, three leads. This change would minimize the chances of error in wiring the jumpers and connections. The degree of complication is greatly simplified when 12 lead motors are involved.

  The motor winding must be tested for any errors in the winding process before it is dipped and varnished. The motor shop should be encouraged to obtain the equipment needed to perform this test, such as a surge comparison tester or motor analyzer and the shop should warrant its work.

  The motor must be tested for operation before it leaves the motor repair shop. All moisture and temperature sensor devices must be installed and tested with each submersible motor, in accordance with the manufacturer's specifications.

  Any motor that has been repaired and will be placed in storage must be wrapped in plastic for protection from dust and moisture.

- Purchase motors for the voltage to be used. Motors should be rated for single voltage with three leads. The chances of error and future failures are higher when multiple connections are made.

  Also, all purchased motors should be of the Totally Enclosed Fan Cooled (TEFC) design, cast iron frame and end bell, Premium Efficiency type and stainless steel (for smaller motor subject to corrosion). Additionally, specify motors with oversized bearings on both the drive and opposite ends.

- Use insulated or ceramic bearings where variable frequency drives are used, at least on one end.

- Obtain a full report from the repair shop, specifying the work done, noting any as-found and as-corrected items and identifying any machine work done with the machined measurements. The data in these reports are to become a part of the maintenance records systems for each piece of equipment.

12.6.11 Energy Savings with Motor Operations

The electrical motor, in itself, is an efficient means to convert electrical energy into mechanical energy. Motors that operate on a continuous basis are large energy consumers and, with savings in the range of a few percent, will reap large returns over the life of the equipment. Such is the case with the deep well motors and aeration blowers.

Most of the facilities observed use the GPA Rate Schedule K (see Exhibit 12A) as a basis for computing the energy costs. This rate schedule takes into account the energy consumed in kilowatt-hours (kWh) and the measured demand; however, no credit is offered for improved power factor correction. An Emergency Water Well and Wastewater Charge is also added to each kWh of energy to handle the GPA operation and maintenance of GPA-owned and operated generators.

As of the date this report was prepared, the total energy charge is approximately $0.17 per kWh and includes the Fuel Recovery Charge adjustment.

Station Y-15 provides an example of energy savings. During August 2005, this station consumed 75,200 kWh of energy with a demand of 112.8 kW. At $0.17 per kWh, this amounts to approximately $12,784 of costs or $153,408 per year. During 2004, the demand charge ranged from 116 to 120 kW with, say, an average of 118 kW.

With the voltage adjustments in place since the beginning of 2005, an average demand reduction of approximately 5.2 kW (118 kW minus 112.8 kW) was realized. With the pump operating 24 hours per day and using a normalized month of 30.4 days, an energy savings of approximately 3,800 kWh could be realized. At $0.17 per kWh, this savings would equate to $646 per month or $7,752 per year. This costs savings would be one of the bases for improving the electrical system to each well, in addition to the cost savings resulting from improved operation with fewer motor failures.

Although this is a simple example, the principles are valid and can be applied to each station.

12.7 Conclusions

This section presents a summary of major conclusions in this chapter.

- A major cause of outages at water wells is determined to be service voltage variation and unbalance, the higher the unbalance the greater the effect on the electrical equipment.
- An increased frequency of operation of the larger horsepower motors increases the mechanical wear on the motor components, such as seals, bearings and shafts, in addition to producing inconsistent hydraulics and flows.
- Continuous system status and alarm condition information has not been available to operations personnel. Failure conditions have been reported by the public rather than being detected by GWA.
- Preventive maintenance has generally consisted of replacing failed equipment with new equipment rather than following a planned preventive maintenance program. Tools are available that can minimize unplanned catastrophic failures and allow for better scheduling of resources.
- Water was observed in the electrical and generator rooms coming from the diesel line wall penetration or from empty raceways. Building security is also a concern since

unauthorized persons have vandalized several stations, as well as the interior of dangerously "live" electrical equipment.

- The percentage phase voltage unbalance is the greatest contributor to deep well motor shutdowns and/or failure. The line voltages have a direct correlation with the phase current and motor losses.

12.8 Recommendations

The implementation and execution of the electrical component of the WRMP is imperative for the successful electrical operation and maintenance of the GWA facilities. The following recommendations are presented for implementing this plan and include specifics for both deep wells and new motor installations:

- Obtain updated voltage, current and power data at each station along with three-day recordings (a minimum of three days is recommended). This information will be used in conjunction with the recordings developed over the past year and provide a second reference point of information.
- Correct the voltage unbalance at all stations to within one percent. This effort will require GPA to balance the distribution line circuits for the stations, assigning priority for critical Northern and Central District water wells. At the same time, replace any damaged lightning arresters and protectors, improve grounding, reconnect transformer secondary conductors (to minimize water entry) and replace conductors (with larger sizing where appropriate).
- At those stations that are served by a WYE-connected transformer bank, ground the transformers at the pole or pad mount.
- Install voltage unbalance relays at the auto transfer switches. This action will allow the equipment (primarily water wells) to continue operating on generator power when the voltage is not balanced. The relay settings would depend on the location and past history of voltage unbalances and on the motor size and loading to determine the in-place safety factor. The target setting would be between one and two percent.
- Install Franklin Electric Sub-Monitors for all deep well motors and install improved motor circuit protectors for all other motors with duty cycles greater than three hours per operation. These devices will serve as the primary protection for the electrical equipment.
- Improve the station grounding to the well shaft. Tie into the GPA power pole and meter ground. Bond metal enclosures and raceways where electricity is installed.
- Install transient surge suppressor protection at the service main disconnect at all stations.
- Prevent water entry into the pump stations. This is a high-priority safety item and can be completed concurrently with the other steps.
- Implement GPA ownership and maintenance of all standby generators and auto transfer switches.
- Use the replaced operational deep well phase monitors at other wastewater and water treatment facilities, where none currently exist, to augment the protection scheme already in place or as a source of spare parts.

- Reactivate and install the SCADA system to monitor equipment operating status.
- Conduct a power factor correction study and install correction capacitors where beneficial.
- Install variable frequency drives at selected waste water pump stations to improve the process flow.
- Initiate design plans to convert the electrical system at each station to a grounded service.
- Train personnel at every opportunity in all aspects of theory, principles of operation, installation practices, maintenance and troubleshooting.
- Incorporate the practices outlined in the current edition of NFPA 70B.

12.8.1 Electrical Testing Procedure for Deep Well Motors

The following are recommended procedures and practices when testing and installing the electrical motors.

- Set up and install the Data Recorder at the motor leads at the starter overload relay. The setting would be for both snapshots and trending. The trending recording would be for approximately 30 minutes, set at a 1-second sample rate.
- The unbalance voltage and current should be computed by the Data Recorder using the phaser diagram setting. Check to ensure that the phase rotation is correct before beginning the recording session.
- Begin recording and take a snapshot of the waveform while on GPA power. Record for approximately 10 minutes.
- Turn Station Main Breaker OFF. This will remove power to the station and start the emergency generator after a time delay. Note the delay period between the time that the power is turned off and the time that the generator starts up.
- Once the transfer switch transfers and the well pump motor starts, take another snapshot after the well water pumps through the bypass valve (if applicable) and again when it pumps into the main line.
- Operate the pump on the generator for at least 15 minutes. Note any abnormal sounds from the generator.
- Turn the Main Breaker ON. Note the length of time between when the breaker is turned ON and when the transfer switch transfers back to normal power.
- Take another snapshot after the return to GPA power.
- Note the time after the transfer switch returns to Normal until the generator is shut down (cool-down period).
- Record all times and readings in a standard test form for future reference.
- Download the recorded data for analysis, particularly during the following conditions:

- Unbalance voltage and current condition (ANSI Method is acceptable) while on GPA power.
- Check the voltage while on the generator power and prior to the starting of the well pump.
- Unbalance voltage and current condition while on the emergency generator.
- Check the time delay settings – power off to generator start, power ON to transfer switch back to normal power and generator cool-down period.
- If there is a large improvement in the current unbalance between GPA power and generator power, then GPA is the source of the unbalance. If there is some improvement but not substantial, then the source is the well motor and wiring. The level of improvement should be an order of magnitude of at least four times and can be determined by taking actual averages of the water system.

12.8.2 Electrical Practice Procedure for New Motor Installation

- Determine root cause of failure for previous motor. Record this information, including digital photos of the exterior and interior, measurements, description of the symptoms and corrective action, etc. and store it with the station file.
- Check motor starter connections. Torque connectors at breaker, motor starter, motor overload and disconnect switch at motor (if available). Torque is to be applied in accordance with the manufacturer's recommendations.
- Inspect motor starter contacts for contact wear area and condition. Use contact burnishing tool to smooth any rough areas. Check alignment for improved contact area.
- For deep well motors, terminate the motor leads with power cable using hydraulic crimper and proper applicable barrel crimp. Encapsulate the terminations and allow the resins to cure.

  For non-submersible connections, install factory crimp eye-type lugs (if not installed) and terminate with nut, bolt and locking washer. Check that the bolt has no sharp parts that can penetrate the insulation.

  After the motor rotation has been determined using the motor tester, insulate the termination as follows:

  - Apply minimum three layers of varnish cambric tape (non-adhesive type)
  - Apply minimum three layers of linerless rubber tape (Scotch 66 or equal)
  - Apply minimum of three layers of PVC tape (Scotch 33 or equal)
- Check voltage prior to starting. Take a photograph to identify and record manner of ground condition.

- Test motor for phase rotation. For a non-submersible motor, test motor rotation and phase rotation before connecting (see bullet 4 above).
- Check motor and controls for proper operation. Check control and timing relays for bypass valve operation.
- For submersible motors, operate motor and measure voltage and current unbalance for this initial setting. Rake motor leads at starter and check current unbalance to obtain lowest current unbalance.

  If current unbalance is out of tolerance or greater than 10 percent, contact GPA to balance transformer voltage before repeating this step.
- Record motor data in maintenance records and apply motor nameplate label at the motor starter cabinet, placing it over the existing label. Note the date of the installation on the label.
- Record the station voltage, current and power for future reference. The power drawn by the motor should not be greater than the motor full-load power rating, in kilowatts (not the service factor power). Record installation with a digital camera.
- Record station power during normal operation for three days and analyze information for any voltage and current anomalies. Coordinate with GPA, as needed.

12.9 CIP Impacts

The 20 year CIP Projects presentation in Volume 1, Chapter 15 – Capital Improvement Program shows expenditures over the period of 2007 – 2011 for major upgrades in the electrical system which addresses specific cost recommendations discussed in this chapter. Specific facility types named in the CIP listing are:

- Electrical upgrades at water booster stations
- Electrical upgrades at water wells
- Electrical upgrades at STPs
- Electrical upgrades at wastewater pump stations

Specific facility information is given for water projects in Volume 2, Chapter 9 – Recommended Water CIP and for wastewater in Volume 3, Chapter 9 – Recommended Wastewater CIP.

Exhibit 12A – GPA Rate Schedule K

Issued March 21, 1984
Revised October 01, 2000
Effective on October 01, 2000

Rate Schedule "K"

GUAM POWER AUTHORITY

SCHEDULE "K"

Small Government Service - Demand

Availability:

Applicable to general light and/or power supplied through a single meter and for residential service with consumption in excess of 200 kilowatt hours per day. A Small Government Demand (Schedule K) customer will be transferred to Small Government Non-Demand (Schedule S) service, if the customer's monthly consumption in each of the customer's last twelve (12) billing months is less than 5,000 Kwh.

A Small Government Demand (Schedule K) customer will be transferred to the Large Government rate schedule (Schedule L), if the customer's billing demand exceeds 200 Kw for either:

(a) any three (3) consecutive months within the customer's last twelve (12) billing months, or

(b) any six (6) of the customer's last (12) billing months.

When transferred to a new rate schedule, the customer must remain on that rate schedule for a minimum of twelve (12) billing months.

Service will be delivered at secondary voltages as specified by the Authority, except that where the nature or location of the customer's load makes delivery at secondary voltage impractical, the Authority may, at its option, deliver the service at a nominal primary voltage as specified by the Authority. Service supplied at primary voltage shall be subject to the special terms and conditions set forth below.

Monthly Rate:

For Single Phase Service:	
First 200 kwhr per kw of billing demand	
First 200 kwhr per month	- per kwhr $0.12905
Over 200 kwhr per month	- per kwhr $0.11421
Next 200 kwhr per kw of billing demand	- per kwhr $0.09067
Over 400 kwhr per kw of billing demand	- per kwhr $0.07104

Exhibit 12A – GPA Rate Schedule K (continued)

Issued March 21, 1984
Revised October 01, 2000
Effective on October 01, 2000

Rate Schedule "K"

SCHEDULE "K" (Continued)

For Three Phase Service:

First 200 kwhr per kw of billing demand	
First 400 kwhr per month	- per kwhr $0.14932
Over 400 kwhr per month	- per kwhr $0.11413
Next 200 kwhr per kw of billing demand	- per kwhr $0.09067
Over 400 kwhr per kw of billing demand	- per kwhr $0.07104
Monthly Customer Charge	$16.19

Determination of Demand:

The maximum demand for each month shall be the maximum average load in kw during any fifteen-minute period as indicated by a demand meter. The billing demand for each month shall be the maximum demand for such monthly but not less than 75% of the greatest maximum demand for the preceding eleven months nor less than 25 kw, for customers with a demand meter. If a customer does not have a demand meter, the billing demand will be the average demand multiplied by the demand factor of 1.4762 that is derived from most recent Load Research Study.

Primary Supply Voltage Service:

Where, at the option of the Authority, the customer takes delivery and/or is metered at the Authority's supply line voltage, the energy charges will be decreased as follows:

Distribution voltage supplied without further transformation	2%
If meter is at the supply line voltage	1%

Fuel Recovery Charge:

The Fuel Recovery Charge, as specified in Schedule "Z", will be added to each bill for service.

Insurance Charge:

An insurance charge of $.00145 per Kwh shall be billed monthly unless suspended by the Authority when Commission insurance reserve criteria have been met. The Authority may reinstate the insurance charge when Commission reinstatement criteria have been met. The insurance charge will be suspended or reinstated in conjunction with the Navy insurance charge.

Exhibit 12A – GPA Rate Schedule K (continued)

Issued March 21, 1984
Revised October 01, 2000
Effective on October 01, 2000

Rate Schedule "K"

SCHEDULE "K" (Continued)

Emergency Water Well and Wastewater Charge:

An emergency water well and wastewater charge of $0.00242 per Kwh will be billed monthly unless otherwise ordered by the Commission.

Rules:

Service supplied under this rate shall be subject to the Service Rules of the Authority.

Riders:

Charges in addition to the above are applicable under certain conditions more specifically set forth and incorporated herein - viz.

Schedule A - Accommodation Service Charges
Schedule B - Service Establishment Charges

Exhibit 12B – NFPA 70B Electrical Maintenance Practices – Section on Voltage Unbalance

in the plant system. *[See ANSI/NEMA C84.1, Electric Power Systems and Equipment, Voltage Ratings (60 Hertz).]*

27.5.1.1 Electric Utilities. Electric utilities can be required by their regulatory commissions to maintain service voltages within prescribed limits for the various types of service. Plant electrical people should be aware of any required service voltage limits for their type of service. The utility generally works with the customer to ensure that the service voltage remains within the required limitations or within their standard design limits where there are no required limitations.

27.5.1.2 As the system load varies, the utility automatic voltage-regulating equipment maintains the service voltage within the required range. When the serving utility's electrical system is severely stressed, the utility can implement a load reduction strategy by reducing the voltage on its distribution lines, typically up to 5 percent. During these periods, the service voltage can be near the lower limit of the required range. As a result, a long-term undervoltage condition can exist at plant utilization equipment. It is strongly recommended that plant distribution system voltage drops be kept to a reasonable level.

27.5.2 Symptoms of Long Duration Undervoltage. Undervoltage might not be readily apparent. Depending on the length and magnitude of the undervoltage, there can be a detrimental effect on electrical and electronic equipment. Equipment such as induction motors might run hotter. Electronic equipment such as computers or microprocessor-based devices can function erratically.

27.5.3 Causes of Long Duration Undervoltage. A long duration undervoltage can originate on the electric utility system or on the plant electrical system. The utility system can be stressed due to line or equipment failure or system load conditions exceeding the supply capability. The plant electrical system or connected loads can result in unacceptable voltage drops even though the voltage is normal at the service point.

27.5.4 Monitoring and Testing of Long Duration Undervoltages. Because the occurrence of a long duration undervoltage might not be obvious, and damage to equipment and systems can result, an appropriate monitoring system is recommended where reliability is vital.

27.5.4.1 The monitoring system can consist of a sophisticated warning scheme with visual and audible alarms at appropriate locations. Alternatively, it can simply be a voltage sensing relay located at the facility service entrance or at sensitive equipment with alarms placed in appropriate locations.

27.5.5 Solutions for Long Duration Undervoltages. When a long duration undervoltage occurs, costly and/or sensitive equipment should be disconnected to prevent possible damage. If it is necessary to keep the equipment or system in operation, then an alternative power supply should be provided.

27.5.6 Symptoms of a Sustained Voltage Interruption. A sustained voltage interruption is obvious because electric power is unavailable for an extended period of time except for equipment served by an alternate power source.

27.5.7 Causes of Sustained Voltage Interruption. Sustained voltage interruptions are caused by power system disruptions such as power lines going down in a storm, the utility's distribution transformer failing, a fault condition causing a circuit protective device to open, or plant wiring problems.

27.5.8 Solutions for Sustained Voltage Interruptions. Solutions include generator sets, multiple power sources, and battery banks.

27.6 Unbalanced Voltages and Single Phasing. *(See 3.3.26 for definition of unbalanced voltages.)*

27.6.1 Percentage Limitations. On 3-phase circuits, unbalanced voltages can cause serious problems, particularly to motors, transformers, and other inductive devices.

27.6.1.1 Single phasing, which is the complete loss of a phase, is the worst-case voltage unbalance condition for a 3-phase circuit.

27.6.1.2 The National Electrical Manufacturers Association (NEMA) in its *Motors and Generators Standards* (MG1) part 14.35, defines voltage unbalance as follows: percent unbalance = 100 ×(maximum voltage deviation from the average voltage) divided by the average voltage.

27.6.1.3 NEMA states that polyphase motors shall operate successfully under running conditions at rated load when the voltage unbalance at the motor terminals does not exceed 1 percent. Also, operation of a motor with more than 5 percent unbalance condition is not recommended, and will probably result in damage to the motor.

27.6.1.4 Example: With line-to-line voltages of 460, 467, and 450, the average is 459, the maximum deviation from average is 9, and the percent unbalance equals 100 × (9/459) = 1.96 percent, which exceeds the 1 percent limit.

27.6.2 Causes of Unbalanced Voltages.

27.6.2.1 Unbalanced voltages usually occur because of variations in the load. When phases are unequally loaded, unbalanced voltages will result because of different impedances.

27.6.2.2 Symptoms and causes of unbalanced voltages include the following:

(1) Unequal impedance in conductors of power supply wiring
(2) Unbalanced distribution of single-phase loads such as lighting
(3) Heavy reactive single-phase loads such as welders
(4) Unbalanced incoming utility supply
(5) Unequal transformer tap settings
(6) Large single-phase load on the system
(7) Open phase on the primary of a 3-phase transformer
(8) Open delta-connected transformer banks
(9) A blown fuse on a 3-phase bank of power factor correction capacitors

27.6.3 Symptoms.

27.6.3.1 The most common symptoms of unbalanced voltages are improper operation of, or damage to, electric motors, power supply wiring, transformers, and generators.

27.6.3.2 Unbalanced voltages at motor terminals can cause phase current unbalance to range from 6 to 10 times the voltage unbalance for a fully loaded motor. As an example, if a voltage unbalance is 2 percent, then current unbalance could be anywhere from 12 percent to 20 percent. This causes motor overcurrent, resulting in excessive heat that shortens motor life.

27.6.3.2.1 The unbalance at the motor terminals will cause speed and torque to be reduced. If the voltage unbalance is great enough, the reduced torque capability might not be adequate for the application. Noise and vibration levels can also increase as a result of voltage unbalance.

27.6.3.3 Motor Heating and Losses. Insulation life is approximately halved for every 18°F (10°C) increase in winding temperature. Table 27.6.3.3 illustrates the typical percentage increases in motor losses and heating for various levels of voltage unbalance.

Exhibit 12B – NFPA 70B Electrical Maintenance Practices – Section on Voltage Unbalance (continued)

Table 27.6.3.3 Voltage Unbalance vs. Temperature Rise at *Average Voltage of 230*

Percent Unbalanced Voltage	Percent Unbalanced Current	Increased Temperature Rise °C
0.3	0.4	0
2.3	17.7	30
5.4	40	40

27.6.3.3.1 The motor often continues to operate with unbalanced voltages; however, its efficiency is reduced. This reduction of efficiency is caused by both increased current (I) and increased resistance (R) due to heating. Essentially, this means that as the resulting losses increase, the heating intensifies rapidly. This can lead to a condition of uncontrollable heat rise, called *thermal runaway*, which results in a rapid deterioration of the winding insulation, ending in winding failure.

27.6.3.4 Motor Operation Under Single-Phase Condition. Single-phase operation of a 3-phase motor will cause overheating due to excessive current and decreased output capability. If the motor is at or near full load when single-phasing occurs, it will not develop enough torque and therefore will stall. This results in high currents, causing an extremely rapid temperature rise. If motor protection is not adequate, the stator winding will fail, and the rotor may be damaged or destroyed.

27.6.3.4.1 Standard (thermal, bimetallic, eutectic alloy) overload relays are normally relied upon to provide protection against single phasing where properly selected and applied. Protective relays or other devices can provide supplemental single-phasing protection.

27.6.4 Monitoring and Testing.

27.6.4.1 The first step in testing for unbalanced voltages should be to measure line-to-line voltages at the machine terminals. If the motor starter is close by, the tests can be made at load or "T" terminals in the starter. The current in each supply phase should be measured to check for current unbalance.

27.6.4.2 Detecting Single Phasing.

27.6.4.2.1 Single phasing should be suspected when a motor fails to start. The voltage should be checked for balanced line-to-line voltages.

27.6.4.2.2 If the motor is running, the voltage and the current in each phase of the circuit should be measured. One phase will carry zero current when a single-phasing condition exists.

27.6.5 Solutions for Unbalanced Voltages.

27.6.5.1 Unbalanced voltages should be corrected; unbalance caused by excessively unequal load distribution among phases can be corrected by balancing the loads. Also, checking for a blown fuse on a 3-phase bank of power factor correction capacitors is recommended.

27.6.5.2 When voltage unbalance exceeds 1 percent, the motor should be derated as indicated by the curve in Figure 2 of NEMA MG 1 *Motors and Generators Standards*.

27.6.5.3 Automatic Voltage Regulator (AVR). AVRs can be used on a per phase basis to correct under- and overvoltage, as well as voltage unbalance. The AVR can compensate for voltage unbalance, provided that the input voltage to the AVR is within its range of magnitude.

27.6.5.4 Relays. Negative sequence voltage relays can detect single phasing, phase-voltage unbalance, and reversal of supply phase rotation. Reverse phase or phase sequence relays provide limited single-phasing protection by preventing the starting of a motor with one phase of the system open.

27.6.5.5 Transformer tap settings should be checked; unequal power transformer tap settings can be a cause of voltage unbalance. This condition should be checked prior to taking other steps.

27.6.5.6 An unsymmetrical transformer bank should be replaced. For example, an open delta bank can be replaced with a three-transformer bank.

27.7 Symptoms — Grounding.

27.7.1 If the equipment ground conductor and the service neutral are not electrically connected to the central grounding point, noise voltages can develop between them and appear as common mode noise.

27.7.1.1 Wiring without an equipment ground conductor and without electrically continuous conduit can produce common mode noise.

27.7.1.2 Ground loops are undesirable because they create a path for noise currents to flow.

27.7.2 Monitoring and Testing — Grounding. The electrical connection to earth can be measured using the three-point system referred to in ANSI/IEEE 142, *Recommended Practice for Grounding of Industrial and Commercial Power Systems* (Green Book). Minimizing the impedance between the equipment grounded conductor and the grounding conductor is recommended, as follows:

(1) A visual inspection should be made to verify the integrity of the grounding and bonding conductors and associated connections.
(2) An impedance test should be performed on the equipment-grounding conductor.
(3) Voltage should be measured between the equipment-grounding conductor and the grounded conductor.
(4) A check should be made for abnormal currents on the equipment-grounding conductor.

27.7.3 Solutions — Grounding.

27.7.3.1 The grounded conductor should be connected to the equipment-grounding conductor only as permitted by NFPA 70, *National Electrical Code*.

27.7.3.2 Isolated Equipment Ground. One solution is to install an "isolated ground" receptacle (identified by orange color or an orange triangle) in which the equipment-grounding terminal is insulated from the mounting strap. An insulated equipment-grounding conductor is then connected from the grounding terminal of the receptacle in accordance with Article 250 of NFPA 70, *National Electrical Code*. The insulated equipment grounding conductor is connected to the applicable derived system or service grounding terminal only at the power source.

27.7.3.3 Isolation Transformer. An isolation transformer has separate primary and secondary windings with an intervinding shield that has its own grounding connection. The bonding jumper between the equipment-grounding conductor and