CHAPTER 12 – ELECTRICAL ASSESSMENT

12.1 Introduction

The purpose of this assessment report is to assist GWA with identifying, correcting, and developing procedures to 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 utilized to identify and locate the sources of the electrical challenges plaguing the consistent operation of GWA services. These included meetings with GWA and GPA personnel; field observations of personnel during equipment troubleshooting, repair, removal and installation; site observations and application of power quality and infrared test equipment; and the analysis of collected data and digital photographs.

The findings indicate the following primary contributing factors:

1. Service Voltage Variation and Unbalance at Water Wells – This item was found to be predominant at the Northern Water Districts with minor incidence in the Central District. The wastewater stations in these districts were also affected but since the pumps operate for short time periods, the voltage effects were minimal.

   Correction of this item with GPA along with installing improved pump motor protection devices and voltage unbalance relays at the auto transfer switches will solve most of the water well failures.

2. Frequency of Operation and Installation of Wastewater Pumps – An increased frequency of operation of the larger horsepower motors increases the mechanical wear on the motor components such as seals, bearings, and shafts besides producing inconsistent hydraulics and flows. This is particularly true when full voltage motor starting is utilized. Pump piping misalignment is also a contributor to mechanical seal failures.

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

3. Lack of Condition Monitoring System – Continuous system status and alarm condition information knowledge was not available to operations personnel. Failure conditions were reported by the general public.

   A SCADA (Supervisory Control and Data Acquisition) system provides this vital link to effective deployment of resources and provides the initial step toward a predictive maintenance program.

4. Lack of Predictive and Preventive Maintenance - Preventive maintenance has generally consisted of replacement with new, after the equipment fails. 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, which in the hands of trained personnel minimize unplanned catastrophic failures and allow for better scheduling of resources.

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Infrared imaging techniques were used during this assessment to locate and, along with the maintenance personnel, prevent several instances where an electrical failure would have occurred within a three month period. Besides its use on electrical systems, infrared can be used on mechanical and hydraulic systems as well, to detect leaks, mechanical wear, etc.

Many of these concepts and practices are also found in NFPA-70B – Recommended Practice for Electrical Equipment Maintenance and other IEEE Publications.

5. Personnel Training – The skill level of personnel in the area of troubleshooting and analysis vary. This has been largely acquired through individual prior experiences and training at other facilities or agencies.

Essential to continuous personnel development is training in skills such as reading blueprints and schematic diagrams, troubleshooting, understanding of the electrical codes and standards, basic electrical theory and principles, etc.

6. 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 need to be repaired. Building security is also an item of concern as unauthorized persons have vandalized several stations as well as the interior of dangerously “live” electrical equipment.

Each facility need be a safe environment for all personnel entering and working in the facility.

7. Other observations and findings are covered in the body of this report. Along with the observations and findings are recommendations for improvement and implementing the major items covered above.

GWA and GPA have made strides toward several of these items covered with an example at 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 insure greater life of this well and water supply.

It is anticipated that this assessment is a step toward the development of a Master Plan 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, and three wire. This system is grounded at the substation transformer; however, the ground or neutral conductor is not extended beyond the station. Any ground faults would rely on the circuit impedance path back to the substation.

Overhead conductors with wooden cross arms on concrete poles are used at almost all 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, and three wire, served through pole mounted transformers. Where the primary electrical system

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is installed underground, pad mounted transformers are used. The transformer neutral was either grounded or ungrounded.

At almost all overhead transformer pole installation, a set of lightning surge arresters are installed to protect the equipment downstream. These are installed between the line and ground and depend on a good ground path to operate properly.

12.2.2 Water Wells

The electrical system at the deep water wells is comprised 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 of the station building. In a few instances, the metering and service masts are embedded within 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, 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 stations visited have generators that are owned and maintained by GPA.

12.2.4 Wastewater Pumping Stations

Most of these 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 utilizes 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 have 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 GPA owned and maintained generators.

12.2.5 Water Treatment Facility

The Water Treatment Facility at Ugum along with the associated river pumping station is powered at 480 volts, three phase, and 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 are backed by standby generators owned and maintained by GWA.

12.2.6 Wastewater Treatment Facility

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

Most facilities have their power to the motors distributed through a motor control center. The larger plants have the motor control centers distributed throughout the facility.

The standby generators are generally owned and operated by GWA.

12.3 Assessment Methodology

The methodology followed to prepare this assessment report was to initially 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 using an AEMC Model 3945 Power Quality Analyzer. Both instantaneous and short term (15 to 60 minute windows) readings were compiled and are found in the Appendix 1.

Infrared imaging techniques were also used to observe the electrical system in operation and for any “hot spots”. This 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 in which images were recorded and downloaded to a PC in jpeg format. Several major abnormalities were observed and, where the electrician was present, immediately corrected.

Vibration readings on randomly selected operational motors that were accessible were also made. Digital photographs of the electrical equipment and sites visited are included. A few of the sites were casually visited. At several locations a number of site visits occurred, hence the photos also cover improvements or replacement of equipment.

From the data compiled, an assessment, shown on Table 12-1, ranging from 0 through 4 was assigned to the various components of the operating system. Each component was given a weight such that this weight multiplied by the assessment value would give a weighted average component.

<table>
<thead>
<tr>
<th>System Rating</th>
<th>Description of Equipment State</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Required equipment is missing or not present. Equipment is Not Operating or Repairable. New Equipment is Required.</td>
</tr>
<tr>
<td>1</td>
<td>Equipment is present but in Poor Condition. Equipment is Not Operating but may be repairable. If repaired, it probably has a short remaining life.</td>
</tr>
<tr>
<td>2</td>
<td>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.</td>
</tr>
<tr>
<td>3</td>
<td>Equipment is present and in Moderate Condition. Equipment is Operational. Routine maintenance being performed.</td>
</tr>
<tr>
<td>4</td>
<td>Equipment is present and in like New Condition Equipment is Operational and newly installed.</td>
</tr>
</tbody>
</table>

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A holistic approach was used to arrive at the weighted average for the station or plant. Consideration was given to the electrical power derived from the Guam Power Authority (GPA) service pole or transformer bank to the electrical conductors and metering, to the building main breaker and the standby generator and transfer switch, regardless of who owns or maintains the equipment.

For the treatment facilities, the assessment covers distribution boards, and specific equipment such as the motor and motor drive. The assessment value in this case is the average value without weighting for each piece of equipment. Since each piece of equipment contributes to the operation of the plant, the average of all equipment was arrived at for the value of the facility.

A tabulation of the station assessment is located in the Appendix 1J.

12.4 Electrical Observations and Findings

In a review of the collected electrical data, site observation, personal interviews, photographs, and manufacturer inquiries, the following issues are 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. A large majority of the station transformer banks were found to be connected using a DELTA configuration. This configuration is normally connected ungrounded.

A few stations where connected using the WYE configuration. This was found to be predominantly connected ungrounded, although this system could be easily grounded. A few of the DELTA configured stations were also found 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). See Figure 12-1 for the unbalance at Station A-10.

DELTA configured transformer banks are used in industrial processes where experienced personnel are involved. An advantage of this connection method is during a transformer failure, the process could continue in an OPEN DELTA configuration at reduced capacity. The ungrounded conductors are coupled to ground using the system capacitance and can be measured using a high impedance meter. If this coupling capacitance is the same, the voltage to ground would be equal. If one of the phases starts to become grounded, the voltage will shift such that at the worst case, the voltage will be 480 volts to ground for the ungrounded phases and zero for the grounded phase.

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 will limit any transient voltages to ground and improve the effectiveness of transient surge suppressors.

Per the 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 which 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 0 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 grounded condition will eventually occur.

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 as 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 3 with ground at those stations where the ground conductor is not installed. Also required are engineered drawings for each station to be submitted to GPA Engineering and the Department of Public Works.

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

Another method of grounding in an ungrounded system is through the use of a zigzag transformer which allows the flow of zero sequence or ground fault currents.
Figure 12-1 is an example of an intentionally grounded center tap delta transformer connection. Note that one of the phase legs in the table (V2) is 409 volts to ground while the other two legs are approximately 240 volts. The single higher voltage phase to ground places stress on that phase conductor as well as requires operators and maintenance personnel to be aware of the higher phase leg.
The condition described in Figure 12-2 is where one of the phase legs (V1) has abnormally gone to a ground condition. The other two phases (V2 and V3) are measured at 462 and 469 volts to ground. The insulation system is stressed to ground at Phase V2 and V3. When either of these two phases goes to ground, a phase to phase short circuit will exist where a high level of fault current will flow.

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 need be implemented as failure is imminent.

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

Also exhibited is a non-sinusoidal waveform denoting the presence of harmonics. 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 and with the unknown being the voltage at the motor termination.

12.4.2 Voltage and Current Unbalance Issues

The percentage phase unbalance (voltage or current) is a number that is calculated by taking a percentage of the greatest variance from the average and dividing it from the average, multiplied by 100% as described below:

\[
\text{% Unbalance} = \left[ \frac{\text{Maximum Deviation from Average}}{\text{Average}} \right] \times 100\%
\]

Equation 12-1: Phase Unbalance Computation Method

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

\[ \% \text{ Voltage Unbalance} = \left[ 3 \times \left( V_{\text{max}} - V_{\text{min}} \right) / (V_a + V_b + V_c) \right] \times 100\% \]

Equation 12-2: 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 which is shown in Equation 12-1, this computational method is being used in this report.

This is an indication of the quantity of the voltage 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. A normal motor is driven using positive sequence currents which rotates in a direction to produce work. Any current unbalance creates a degree of negative sequence currents that flow in the opposite direction with the same frequency or counter to producing work. The net effect is a force that is driving the motor in the opposite direction and simulates a braking action similar to driving a car with one foot on the accelerator and the other on the brake and is counterproductive.

The motor needs to overcome this braking effect and hence operates with reduced efficiency and greater heat generation which seriously decrease motor insulation life. This 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 primarily because of the compact nature of the motor with little space allocated for heat dissipation (approximately 50 horsepower in an 8 inch diameter frame for example).

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

The losses within the motor equates to approximately two times the square of the voltage unbalance. For example, a voltage unbalance of 2% is equal to a loss of approximately 8% or for 3%, an 18% loss. This is a substantial energy cost in comparison to the water or end produce delivered.

The following figures are excerpts from NFPA 70B – Electrical Equipment Maintenance, Section 27.6 relating to Unbalanced Voltages and Single Phasing, its causes, effects, and possible solutions for corrective action to substantiate the findings herein.

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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 limits 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 in the electric utility system or on the plant electrical system. The utility system can be stressed by one or more 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 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 auditory alarms at appropriate locations. Alternatively, it can be a voltage sensing relay located at the facility service entrance or at sensitive equipment with alarms placed at 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 voltage.)

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 18.35, defines voltage unbalance as follows: percent unbalance = \[ 100 \times \left( \frac{\text{maximum voltage deviation from the average voltage}}{\text{average voltage}} \right) \] 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 400, 467, and 450, the average is 459, the maximum deviation from average is 9, and the percent unbalance equals 100 \times \left( \frac{9}{459} \right) = 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 50 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.
Table 27.6.3.3 Voltage Unbalance vs. Temperature Rise at Average Voltage of 230

<table>
<thead>
<tr>
<th>Percent Balanced Voltage</th>
<th>Percent Unbalanced Current</th>
<th>Increased Temperature Rise °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>2.3</td>
<td>17.7</td>
<td>30</td>
</tr>
<tr>
<td>5.4</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

27.6.3.1 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.

27.6.4.3 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 thereby 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 S-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, providing 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 the state 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.

27.7.1.1 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.

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

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

27.7.3.2 Monitoring and Testing — Grounding. The electrical connection to earth can be measured using the three-point system referred to in ANSI/IEEE 492, Recommended Practice for Grounding of Industrial and Commercial Power Systems (Green Book). Minimizing the impedance between the equipment grounding 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 device or service ground terminal only at the power source.

27.7.3.3 Isolation Transformer. An isolation transformer has separate primary and secondary windings with an interwinding shield that has its own grounding connection. The bonding jumper between the equipment-grounding conductor and
Table 12-2 illustrates spot voltage and current readings as well as corresponding unbalances and power and power factor readings taken at Water Pumping Station Y-15 during 2004 and early 2005.

<table>
<thead>
<tr>
<th>Reading Date</th>
<th>Voltage</th>
<th>%Unbal</th>
<th>Current (Amps)</th>
<th>%Unbal</th>
<th>KW</th>
<th>PF</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/30/04</td>
<td>462.0</td>
<td>1.8%</td>
<td>142.5</td>
<td>12.1%</td>
<td>109.3</td>
<td>.82</td>
</tr>
<tr>
<td>08/25/04</td>
<td>475.4</td>
<td>1.3%</td>
<td>155.2</td>
<td>14.7%</td>
<td>105.5</td>
<td>.82</td>
</tr>
<tr>
<td>10/22/04</td>
<td>462.6</td>
<td>1.5%</td>
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<td>.83</td>
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<td>111.5</td>
<td>.82</td>
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The 125 HP deep well submersible motor failed in July and December of 2004. The August 25th recording was taken after the motor was replaced in July. The October recording was with the same motor and the January recording was after the motor was replaced again. No recordings were taken when a new motor was installed in December, with the motor failure after 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 KW. With the service factor of 1.15, the maximum current is 188 amps and 125 KW.

Although these were spot readings and different manufacturers’ motors were involved, they are representative of what was occurring at the station at the time the readings were taken (during the day). Recordings during the evening were not made nor were recordings over a three day or longer period.

From the data collected, most of these challenges were observed in the areas affecting the F, D, and M Water Wells, although each need be addressed on a case by case basis. A primary factor being well fields which 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.

Correcting or dealing with this single item of voltage unbalance will yield one of the highest returns to GWA and GPA in improved water pumping efficiency and increased electrical revenue.

Most of the wastewater pumping stations in the same area as the water wells are less affected, despite the unbalance voltage, because the pumps are operated only for a short period of time, usually less than 10 minutes, which is insufficient time for heat generation.

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, that operate continuously, are affected, however.
In Figure 12-4 above, these are typical voltage readings to ground which shows 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 see if a shift in voltage to ground continues which is an indication of a failure of the insulation level on the phase with the lower voltage, as in Figure 12-3. Note also the slight presence of voltage harmonics on the sinusoidal fundamental waveform.

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.
In Figure 12-5, this is the voltage provided to the motor. The voltage unbalance is calculated as follows:

\[
\text{Average Voltage} = \frac{466 + 465 + 481}{3} = 470.6 \text{ Volts}
\]
\[
\% \text{ Voltage Unbalance} = \left[\frac{481 - 470.6}{470.6}\right] \times 100\% = 2.2\%
\]

In this case, despite the voltage variation, that provided to the motor exhibit a sinusoidal waveform. With only this observation and despite the unbalance, it would appear that the phase voltages are fine while the condition in Figure 12-4 exist between the phase and ground, hence the importance for making visual phase to ground readings using an instrument such as the AEMC 3645.
Figure 12-6 shows the corresponding current during the same period as the voltage recording in Figure 12-4 (phase to ground) and 12-5 (phase to phase).

The current unbalance is computed as follows:

\[
\text{Average Current} = \frac{(68 + 57 + 75)}{3} = 66.6 \text{ Amps}
\]

\[
\% \text{ Current Unbalance} = \left( \frac{66.6 - 57}{66.6} \right) \times 100\% = 14.4\%
\]

Despite the variables dealing with motor and installation practices, this depicts the relationship between voltage and current where a voltage unbalance affects a consequent current unbalance.
In Figure 12-7, the station was operated on the emergency generator and the voltage recorded. This recording should be compared with Figure 12-4 (on GPA power). Note the balanced voltage to ground resulting from a grounded WYE connection within the generator. The corresponding voltage unbalance is noted to be 0.1%.

This is an indication that the voltage unbalance (2.2% on GPA power and 0.1% on generator power) is largely attributable to the transformer voltage unbalance and service conductors. This is a good test method to determine the source of unbalance.

Figure 12-8 shows the corresponding phase to phase voltage that the motor would be provided when operated on the emergency generator. The corresponding voltage unbalance is 0.1%.

Although the phase current was not measured because the pump was not operated during this test, the balanced voltage will be the first step to determine 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 for a detail of this procedure.

A three day recording was made at Station M-20A in May of 2005 which provided valuable information on the operation of the electrical system. The voltage recording showed a wide voltage swing (490 volts to 445 volts). This was investigated by GPA and found to be caused by manual tap changer changes at the sub-station transformer. (As of August 2005, information was received that the tap changer, which normally operates automatically to adjust the voltage, was being repaired).

**Figure 12-9 – 3 Day Trend Recording – M-20A – May 24-27, 2005**

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 be studied, coordinated, and adjusted.

**12.4.3 Electrical Meter Failures**

At several locations, failure of the meter socket occurred. This was caused primarily by a flashover between the phase to phase conductors and/or ground.

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.

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12-18
themselves. In 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.

Figure 12-10 – Electrical Meter Failure

In instances where self contained meters are used, the corrosion will appear at the metering terminals. Where current transformers are used, moisture has occurred at the main breakers instead. This process may take several years before an adequate amount of water develops.

GPA Practices already incorporate the installation of transformer wiring terminations such that the conductors are looped upward and consequently new installations incorporate this change. The existing installations need to be corrected with high priority attention. Almost all presently installed service conductors are subject to this condition and need be replaced rather than just re-terminated. This replacement is necessary as each failure occurs as well as when the transformer connections are reworked.

A visual inspection by the GPA metering personnel is recommended. Stations with any sign of moisture or corrosion in the meter socket should be given a higher priority.
Conductors using XHHW or RHW insulation are better equipped to handle this situation.
12.4.4 Motor Overload Protection

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

Relating to water wells, the Franklin Electric Company (which supplies the majority of the deep well pumps) recommends the use of Class 10 overload protection response which is faster than that of a Class 20 and better suited for this application.

In the operating condition experienced and due largely to voltage unbalances, one current leg is generally higher than the other two. If the Class 10 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 simulates the condition within the motor or equipment it is protecting) and adjust for the unbalanced current. This is not an ideal solution but can provide a temporary compromise from nuisance tripping providing the motor full load ratings are not exceeded. The Class 10 relay has only one adjustment, making this 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 their Sub-monitor Premium unit. The sensor in the motor has the ability to communicate with the motor protector through the power wiring and hence shut the motor down in an abnormal temperature 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 pumping station is recommended. This will allow for the automatic starting of the generator and a transfer to generator power until the voltage situation is corrected. This will continue to provide the desired product (water) as opposed to using a voltage unbalance relay at the pump, which will cause to pump to shut down (lack of water).

The transfer switches need be locked such that this sensing relay cannot be tampered with except by personnel authorized to make changes. The GPA operated generator stations have their transfer switches locked.

12.4.5 Phase Monitor or Motor Protectors

Several stations were equipped with phase monitors to monitor the effects of voltage loss, reversal, and over or under voltage conditions. Monitors are also available on the market that monitors the unbalanced current as well. These monitors were generally connected at the line side of the motor starter (Timemark C263 and Linebacker 600 Series) or across the motor starter (Linebacker 800 Series). These electronic sensor relays are generally not well suited for unbalanced voltage or current but offer a faster response to single phasing conditions than the Class 20 motor overload relay.
These monitors are limited in their effectiveness when valid nuisance tripping occurs, causing the shutdown of the pump or motor after which personnel would alter or bypass the settings to prevent callouts.

These units are not well suited for the deep well motor challenges and should be applied with other motors within the system.

12.4.6 Reduced Voltage Motor Starting

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

Reducing the voltage decreases the current and resulting mechanical stress. The most common method of reducing the voltage has been through the use of an adjustable autotransformer. This is a timed one voltage step (usually 65% or 80% of full voltage) 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 electronic reduced voltage motor starting. These starters have the ability to provide fairly smooth motor starting and stopping by allowing the applied voltage to be ramped over time. These are particularly beneficial where high mechanical torque is applied on a frequent basis, where controlled by discreet level devices. The ramping will also reduce the hydraulic stress on the water and wastewater system piping and check valves.

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

These starters require a contactor to by-pass the reduced voltage electronics when the motor is operating at rated speed. In a few models, the contactor is capable of starting the motor in an across the line mode as a back-up. This is not a recommended mode of operation, however, is essential for continued operation.

The use of this starter type was observed at the Fujita and Route 16 Wastewater Pumping Stations. Both are good applications. At several stations, the autotransformer had burned and a full voltage starter was installed. The burning of the autotransformer is likely caused by overheating due to a failed starter timing relay. In the deep well applications, the long motor lead wire can act as a resistor to automatically limit the current and voltage to the pump.

12.4.7 Motor Oversizing

Another practice of 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 station show 40 horsepower motors. These were found to have a 50 HP motor installed. This 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.

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

From the data collected using 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. This is reflected in higher losses and costs of operation.

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

The power quality analyzer equipment is capable of recording the power (real and imaginary) required by the motor. This data is valuable because it is 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 were owned and maintained by GPA, whereas most of the wastewater station had generators owned and maintained by GWA. The GPA generators were mostly manufactured by Generac or Caterpillar. The GWA units varied from Kohler, Onan, Generac, Caterpillar, and others.

Most of the GWA units observed at the water and wastewater pumping stations did not have the battery installed and hence would not operate during an unscheduled power outage. Other than those that were under repair, generator units at the treatment plants were equipped to operate during an outage.

At one of the stations, Y-1, the generator cover was removed and wiring traced such that the neutral of the generator was grounded to the system ground. At other stations, the generator internal connections appear to be a solidly grounded from the voltage to ground measurements observed. The generator voltage is 480Y/277 volts, grounded, while the service voltage is 480 volts, ungrounded. This is an apparent conflict in operating the generator when there is a ground on the ungrounded system whenever a ground fault condition is present. The protective device will trip or further damage will occur to the grounded device.

12.4.9 Diesel Fuel Line Building Wall Penetration

At several water pumping stations, water entry into the electrical and generator rooms was evident, 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. The resulting condition creates an electrical safety hazard to all personnel entering and working due to the wet floor environment.
The water in the diesel fuel trench and storage containment area also expedites the corrosion of the fuel lines to the generator. This could affect the proper operation of the generator in the future or allow water entry into the fuel system.

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

Additionally, at a few stations water entry was noted in the electrical room due to the electrical control raceways being located at a higher elevation and in the vicinity of the well head. These raceways returning to the electrical control cabinets were at a lower elevation. Stations where the diesel fuel tank was located within its own containment area within the building were not affected.

12.4.10 Coordination with Guam Power Authority (GPA)

The identification and analysis of electrical challenges at GWA Facilities requires a working cooperative relationship with GPA in solving 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 hence a voltage of 480 volts at the motor starter should assure that the correct voltage is delivered at the motor.

The sizing of the motor cable conductors need follow the manufacturers’ recommendation and is found in the service manual for the motor size installed.

What may be more meaningful is the recording of the power supplied to the motor, measured in kilowatts. 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 is 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 failure susceptibility. 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 were the motor loading was in the motor service factor range have a higher probability of failure and several failed during the assessment period. See the pump station summary in Appendix 1J.

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

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 suppressors (TVSS). Both issues of grounding and bonding of the electrical components, beginning with the utility equipment to the well pump, are necessary and must be addressed.

Presently, as observed at most stations, the utility transformer grounding system is separate from that of the well. Also, the station building grounding system is separate from the well,
except 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 and apparently a victim of theft.

In the Northern area, the ground resistance was measured with relatively high ohmic readings (in the 130 ohm range). This was likely due to the type of soil conditions present at the time the reading was made, 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 the best ground at the deep water wells as this is conductive to the ground water. Using this as the ground for the site would be advantageous; however, grounding and bonding conductors need 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 need be considered if additional electronic equipment is to be incorporated into the facilities.

Lightning strikes directly affect the power system and need be dissipated in a safe manner to minimize any hazard to personnel. Most of the GPA transformer power poles utilize lightning arresters to dissipate the energy to ground; however, several stations were observed with missing or “blown” lightning arresters. Missing or high impedance ground connections are also a detriment to effective suppression.

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

This was evident at station HG-2A when one of the transformers faulted to ground. When one of the fuses was replaced, the 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 a result of the high impedance of the return path. This issue, however, is one that need be investigated by GPA.
This is the first line of defense to the stations protection.

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 seem to occur during or after an electrical lightning storm.

We recommend the installation of a tiered transient voltage surge suppression (TVSS) system at all facilities. A tiered system is one that would provide levels of protection as follows:

1. Service Entrance Equipment – Larger Unit at the Main Breaker
2. At the protected device, critical motors, devices and motors over 50 HP in size.
3. All electronic or computer devices

This would apply to GWA offices as well.

The TVSS units are to be equipped with replaceable modules of standardized sizes. Attention need be noted on the location and type of electrical system the unit is to be installed (WYE or Delta). 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 to produce effective work. Induction motors need reactive power to operate. This reactive power however, does not produce work. It does increase the apparent power (KVA) that the electrical system must provide whether this is from the generator, synchronous condenser, or power factor correction bank. This increased apparent power increase the system losses and voltage drop.
Power factor capacitors serve as a source of capacitive reactive VARs (Volt Amp Reactive) to counteract the motor's source of inductive reactive VARs. By supplying a portion of the VARs at the well or pump station, this helps to improve the voltage and reduce the current.

The power factor measured at the various facilities ranged from a low to high 80% range with the ideal at 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 facilities are under the 200 KW demand range and are billed at GPA Schedule K—Small Government Service rate structure (see Figure 10) and do not benefit from an improvement by power factor correction. An improvement in voltage stabilization is the benefit separate from billing credit. The large demand (greater than 200 KW) facilities would benefit by this improvement when greater than 87% by a 0.15% credit per point reduction. For example, a facility that presently has an 80% power factor would have a 0.45% penalty changed to a 1.2% credit when the average power factor is improved to 95%. This is a net change, monthly credit of 1.65% 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 at all stations greater than 50 HP in rating is recommended. Also this needs to be connected to operate with the driven piece of equipment.

### 12.5 Electrical Assessment

The following are the summary sheets of the Water and Wastewater Station Assessment:

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Utility Service Info</th>
<th>Building Service Info</th>
<th>Standby Generator</th>
<th>Pri. Pump Motor Ctrl</th>
<th>Sec. Pump Motor Ctrl</th>
<th>Chlorination Motor Starter</th>
<th>Pump Controls</th>
<th>Building Electrical</th>
<th>Assessment Value</th>
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12-28
Table 12-3 – Wastewater Pump Station Assessment Summary (continued)

<table>
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<th>Station Name</th>
<th>Utility Service Info</th>
<th>Building Service Info</th>
<th>Standby Generator</th>
<th>Pri. Pump Motor Ctrl</th>
<th>Sec. Pump Motor Ctrl</th>
<th>Chlorination Motor Starter</th>
<th>Pump Controls</th>
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“This is a draft report and is not intended to be a final representation of the work done or recommendations made by Brown and Caldwell. It should not be relied upon; consult the final report.”
Table 12-4 – Water Pump Station Assessment Summary

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12-30
Table 12-4 – Water Pump Station Assessment Summary (continued)

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<td>0.15</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>M-03</td>
<td>0.2</td>
<td>0.45 0.575</td>
<td>0.75</td>
<td>0</td>
<td>0.045</td>
<td>0.15</td>
<td>2.4</td>
<td></td>
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<tr>
<td>M-06</td>
<td>0.425</td>
<td>0.45 0.6</td>
<td>0.55</td>
<td>0.07</td>
<td>0.05</td>
<td>0.15</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>M-09</td>
<td>0.475</td>
<td>0.45 0.5</td>
<td>0.75</td>
<td>0.14</td>
<td>0.06</td>
<td>0.15</td>
<td>2.5</td>
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</tr>
<tr>
<td>M-15</td>
<td>0.6</td>
<td>0.45 0.55</td>
<td>0.6</td>
<td>0.12</td>
<td>0.085</td>
<td>0.12</td>
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<tr>
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<td>0.6 0.575</td>
<td>0.75</td>
<td>0.12</td>
<td>0.05</td>
<td>0.12</td>
<td>2.7</td>
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</tr>
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<td>M-18</td>
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<td>0.6</td>
<td>0.12</td>
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<td>0.1</td>
<td>2.4</td>
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<tr>
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<td>0.7</td>
<td>0.12</td>
<td>0.055</td>
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<td></td>
</tr>
<tr>
<td>M-23</td>
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<td>0.45 0.5</td>
<td>0.75</td>
<td>0.11</td>
<td>0.085</td>
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<td>0.55</td>
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</tr>
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<td>0.55</td>
<td>0.12</td>
<td>0.08</td>
<td>0.15</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Y-09</td>
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<td>0.45 0.575</td>
<td>0.6</td>
<td>0.12</td>
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<td>0.15</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Y-23</td>
<td>0.6</td>
<td>0.45 0.35</td>
<td>0.7</td>
<td>0.14</td>
<td>0.1</td>
<td>0.15</td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

The final assessment, as shown in the right column, is the weighted average of each of the different areas and as described in the Assessment Rating Scale Table on page 12-10. The detailed assessment sheets are located in Appendix 1J.

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

The detailed assessment sheets also include comments on the findings in the far right column following the comment guide.

12.6 Recommendations and Budgetary Costs

The following are recommendations, budgetary costs, and implementation ideas, based on the observations and findings:

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. From this data and site observations, a station punch list for corrective action and identifying an individual point of contact is recommended to be developed. The development of an internal GWA Quality Circle Group comprising electrical, engineering, and operations personnel from water and wastewater to identify areas requiring attention is also recommended. This group would also

“This is a draft report and is not intended to be a final representation of the work done or recommendations made by Brown and Caldwell. It should not be relied upon; consult the final report.”
include meetings with GPA, recommended on a monthly basis, to update corrective and future work progress and review current electrical challenges.

It would be advantageous to have members of this focus group attend electrical conferences to share and expand the individual and group skill level in solving electrical challenges. Suggestions for training and conferences are covered in a later section.

The cooperative effort at Water Pumping Station Y-15 during January of 2005 following a recent motor failure (basically the fourth for the 2004 year) is an example. 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% and the motor current unbalance to approximately 2.2%. Involved in this incident were the combined pooling of personnel from GWA, GPA, Vendors, and Earth Tech.

**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 with the water increasing the hazardous condition. This 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 and attached to the generator building.

GPA is presently working on relocating the diesel fuel line as evidenced at several stations. At those stations where GWA generators were involved, the diesel fuel tank and lines were installed within the building and are not an issue.

We recommend the installation of a chemical valve that would allow water to flow through and not the diesel oil. The valve will solidify if any oil product comes in contact with the chemical cartridge. The cartridge is then replaced and sent to the landfill. This is a commercially available item. The cost for this item is not known as of this report date.

This item is a priority safety issue requiring immediate attention with the cost estimated at $1,000 per station that requires this work. In the meetings with GPA, the lines would be relocated by the GPA generator crew.

**12.6.3 Power Quality Issues**

Several items relating to the quality of power follow:

**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 phase voltage has a direct correlation with the phase current and motor losses. The motor manufacturer (Franklin Electric) and the National Electrical Manufacturers Association (NEMA) recommend no greater than a 1% voltage unbalance for operation of motors. This is most evident with the deep well submersible motors and less of a factor with those that are ambient air cooled.

The installation of higher horsepower motors to account for this braking effect results in a higher unit operating cost.

From the data recordings, not all water well stations experienced this condition. Most evident are stations that affect the F, D, and M Water wells. It is recommend...
that those stations with a voltage unbalance of greater than 1.5% have priority by having the transformer bank adjusted with the goal of less than 1% unbalance. The reworking of the service conductor termination at the transformer would be performed at the same time, as well as any corrections with grounding and lightning arresters.

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

We recommend that each deep well motor, presently installed or new installation, be checked for its minimum unbalance condition by raking the motor leads. This technique need be performed each time the motor conditions change.

We recommend the installation of a voltage relay specifically manufactured for monitoring voltage unbalance. This unit need be adjustable and have a 1% to 5% range with a maximum 20 second time delay. Units in the 1 to 10% range would not provide the refinement needed. These relays would monitor the utility voltage unbalance only and 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% adjustment range is recommended.

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.

The installation of these voltage relays are a high priority item.

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 this duration is an issue as the cabinets often times cannot be locked. A means to pursue further recording of this data is essential to better analyze the power at a station. The voltage differences between day and night could be significant and affect pump performance. This data would also be valuable to GPA in improving their service.

The recordings at Station M-20A in May 2005 reinforce the need for this data collection as the voltage swing was significant and visually showed the switching of effects of capacitors on the GPA system.

We recommend 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

Observed at several sites were missing or ungrounded surge arresters at the utility pole. These form the first line of defense again power surges and lightning. These are primarily for limiting the surge to the transformer bank. Depending on the transformer Breakdown Insulation Level (BIL), a large portion 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. Little or no secondary surge protection units were observed. A few that were installed were not operational.

It is recommended that secondary transient voltage surge suppression (TVSS) protection be installed at the building service and to an established grounding system. Consideration must be given to the transformer connection type (WYE or DELTA and grounded or ungrounded) and 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 lighting surges is vital to the protection system. Bonding or the connecting of all metal parts to minimize any potential differences between equipment is also critical for safety. Hence grounding and bonding are interrelated for safe operation.

We highly recommend the use of the well shaft casing, at the water wells, to serve as the primary ground at each facility. All other items are to be connected to a copper ground bus (located within the station building) and 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 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. With the improvements in station grounding and application of surge protection devices we recommend 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 transient voltage surge suppression units for a grounded system need to be applied.

A cautious warning to note when converting the present ungrounded DELTA transformer bank to a grounded WYE is to check for the presence of an existing ground or shift in neutral point to ground. This need be cleared and corrected prior to energizing the WYE system as failure to do so will produce ground faults to flow.

Ground detectors, 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 those locations.
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 CT metering is used.

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

The wiring method at the transformer need be corrected so further water would not enter the conductors. These conductors need be identified for replacement when the transformer bank is scheduled for replacement.

We also recommend the use of type XHHW insulated wire for the service conductors. The conductor size would be as follows:

<table>
<thead>
<tr>
<th>Station Breaker</th>
<th>Station HP</th>
<th>Conductor Size</th>
<th>Meter Socket Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 A</td>
<td>50 HP or less</td>
<td>#1 AWG</td>
<td>200 A – Self Contained</td>
</tr>
<tr>
<td>225 A</td>
<td>75 and 100 HP</td>
<td>#4/0 AWG</td>
<td>200 A – Self Contained</td>
</tr>
<tr>
<td>400 A</td>
<td>125 HP to 200 HP</td>
<td>#500 MCM</td>
<td>CT Rated</td>
</tr>
</tbody>
</table>

We recommended the minimum size conductor for any electrical service be rated for 100A, #1 AWG.

We also recommend that as a minimum, 200A self-contained meter sockets be installed 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 above ground applications; however, it is not recommended for the submersible deep well pumps primarily due to its response time. Recommended is a Class 10 unit which has a faster response time.

GWA has initiated the installation of motor protector relays with adjustable overload classifications. These units use 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 (CT) while the “Motor Saver” unit does. This is
somewhat of a disadvantage because the correct CT need be procured and wound into the unit and 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 what this implies is that the motor would be shut down to protect itself in a greater occurrence than how it is applied. Hence, 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 shut downs will consequently increase. Tampering with the settings is not the recommended solution, but may be necessary to maintain operation.

We recommend 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 as long as the voltage is unbalanced. This will provide the best overall protection for the continued water production of the well motor.

The unit cost is estimated to be in the $1,000 to $1,500 range for the procurement and installation of the “Premium Sub-monitor” model.

**Motor Oversizing** – Installing a larger motor than that which is required for the station is another means to account for the voltage unbalance condition. This may have been indirectly done in the process of keeping the deep well motors from prematurely failing. This has been at the expense of decreased efficiency of operation.

We recommend the review of the pump hydraulics for each of the deep wells to determine the proper sizing of the pump and motor. We also recommend these motors to be oversized by one size larger with the objective to have the motor operate 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 re-checked with the new parameters.

**Phase Monitor or Motor Protectors** – Phase monitors and motor protectors such as the Timemark, Linebacker, and the Motor Saver Series are presently installed at many sites and serve a role to minimize motor failures due to loss or reversal of phase voltage as well as high or low voltage conditions. These should be applied at all motors critical to system operation; however, except for the Motor Saver, they have limitations with the deep well motors.

We recommend that for the deep well motors, the Franklin Electric Premium “Sub-monitor” or its direct equivalent be used because it will serve all of the functions of the phase monitors above as well as monitor the phase unbalance currents and voltage and the motor temperature, in a single package. The Timemark and Linebacker phase monitors could be removed and re-used at the Water Booster Pumping Stations and Treatment Plant. The remaining units are to be used at the Wastewater pumping and Treatment Facilities, such that all motors are protected.
The Linebacker 800 Series or the Motor Saver or the Franklin Electric Standard “Sub-Monitor” or their equivalent, are recommended to be used 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, etc. similar to the phase monitors presently in use. Further protection is offered as motors that are shorted will be sensed by the electronic circuitry and not be operated. These also have the ability to limit and ramp the starting current for a softer start and hence produce less mechanical stress on the pump and are particularly beneficial for the larger horsepower motors with a high frequency of operation.

We recommend the installation of electronic reduced voltage starters with a full horsepower rated by-pass contactor with on and off ramping functions, for all motors greater than 100 horsepower in size. This is to limit the mechanical stress on the motor. Where these units are to be installed in an existing motor control cabinet, the enclosure need be protected from the environment and preferably gasketed. The raceways entering the enclosure are recommended to be sealed with duct seal to prevent the entry of insects and vermin.

We also recommend the use of electronic reduced voltage starters for motors greater than 30 horsepower that have a high frequency of operation (6 starts or more per hour). These starters should also be equipped with a full rated horsepower by-pass contactor and adjustable ramping functions.

The budgetary costs for these starters will vary based on the motor size but generally the difference between autotransformer start and electronic are comparable for units greater than 100 horsepower.

**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.

We recommend the installation of power factor capacitors for all stations motors 50 HP or greater in size. The capacitors would be approximately 10 to 15 KVAR in size, depending on the loading and station power factor.

Power factor correction capacitors that are oil filled as opposed to those having an electrolyte are recommended. Also units that have smaller individual capacitors in parallel are recommended as an individual failed capacitor could be replaced as opposed to replacing the entire unit. Oil capacitors have a higher breakdown rating and are self healing. The capacitor unit should also have indicating 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, it 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 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 at $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 by-pass condition to purge the well until the laboratory test results clear the well to be put on-line. At times, the by-pass valve is operated in a fully open position. Because the well head pressure is at its minimum, the motor has been observed to carry full or greater than full load. During this assessment period, a new motor was lost while operating in the by-pass mode.

We recommend that the hydraulic design for each well be reviewed to match the system requirements. Until such time, we recommend that the pump current load be checked while in this by-pass mode and personnel be instructed to limit the manual valve position.

**12.6.5.4 GPA Operation and Maintenance of Generators**

From the observations and as a general rule, the stations operated and maintained by GPA Maintenance Technicians were 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. The batteries were then removed for storage.

Several wastewater pumping stations did not have an operational generator. Either the generator was missing, damaged, or without a battery. These generators are planned to be replaced shortly.

We recommend that the operation and maintenance of all generators (including those office facilities) be performed by the GPA Generator Personnel. This will involve standardizing on units for spare parts and training with others in the inventory.

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

**12.6.5.5 Aluminum Service Conductor Usage**

For consideration as a deterrent is the use of aluminum service conductors in areas where a high degree of conductor theft has occurred. The proper treatment of and use of anti-oxidizing compounds on the terminations is essential to maintain service without incidence.

Aluminum conductors are less flexible to handle and hence the bending radius need be observed when installing raceways.
12.6.5.6 Predictive and Preventative Maintenance Program

Periodic Maintenance and Testing - With proper test equipment and training, GWA staff can implement a preventive and predictive maintenance program.

The initial source of information is from the equipment manufacturer’s instruction and operating manuals. This is usually provided for each equipment item in hard copy format. In many instances, digital electronic files are available on compact disc (CD), digital video disk (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 the use of NFPA 70B – Recommended Practice for Electrical Equipment Maintenance (latest Edition) produced by the National Fire Protection Association. This publication is a wealth of information on electrical equipment maintenance principles and practices, prepared maintenance forms, and testing procedures and methodologies.

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

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 (6 or more starts per hour) the motor starter contact and terminations need be checked on a frequency basis, for example quarterly, for wear. Worn contacts need be replaced with new or re-conditioned contacts.

There were a few cases where moisture 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

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

The following equipment is recommended, as a minimum:

- Voltmeter (True RMS)
- Ammeter (True RMS)
- Megohmmeter (1000V)
- Power Quality Analyzer
- Infrared Imager
- Vibration Analyzer (Also capable of balancing)
- Motor Analyzer and Tester (Surge Comparison Tester)
- Alignment Tools (Laser as well as gauge type)
Safety Insulated Hand Tools, Gloves, and 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. It should be noted that only True RMS meters should be used for these purposes as inaccuracies could develop when non-linear waveforms are attempted to be measured.

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

**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 DC voltages to 1000 volts is recommended. Care must be exercised when applying this voltage to electronic devices.

Besides insulation resistance (value taken at one minute of test), a Polarization Index (the ratio of the value taken at ten minutes divided by the value at one minute) and Dielectric Absorption (value at three minutes divided by 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 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 need be capable of sample rates in the 256 times per cycle range to be effective as well as 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 on 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, in many cases long before any failure occurs. The condition being that the equipment to be evaluated must be operational during the assessment period.

During this assessment, several potential electrical failures were averted through the use of this technique as nuisance tripping of overload relays due to overheated terminations were noted. Oftentimes after a trip, the connection had cooled down by the time the maintenance personnel arrived so the unit was reset and operated again only to trip again. Hence in some cases, the overload heater size was increased to keep this from failing and compromising the protected equipment.

The cost of these instruments has been dropping with improvements in technology. We recommend the Flir E Model series because of its real time display and light weight.
Vibration Analyzer – Bearing failures are attributed to over 50% of motor and equipment failures. Delving into the mechanical world where frequencies are greater than that sensed by human touch is an early predictor, such as the impact of ball bearings within its 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 use Fast Fourier Transforms (FFT) technology to break the raw accelerometer readings into their respective frequency components.

The test instrument need be capable of performing field balancing as well as check alignment practices, where laser alignment is not used. It is a good practice that all motors except the deep well motors, operating at 3600 rpm synchronous speed, be aligned and checked for vibration after it is installed. This data will form the basis for the historical record for that 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 a static and dynamic...
look into the motor. Such items as failed stator or rotor bars, stator winding abnormalities (particularly after it has been rewound), phase and slot insulation integrity, static rotational indication, and others can be performed.

This tool can enhance maintenance determinations as to whether a motor could be re-used after a removal.

**Alignment Tools** – The mechanical life of equipment is a direct relationship to the degree of alignment of the drive and the device. The time expended in the use of mechanical gauges for alignment often can be shortened by the use of laser alignment tools with substantially better accuracy. Any alignment settings need be recorded for historical purposes.

Improved bearing life is a contributed result of correct alignment.

### 12.6.6 Training

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

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

- Basic and Advanced Electrical Theory and Circuitry
- Electrical Motor Controls
- Electrical Motors, Transformers, Drives
- Electrical Safety
- 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 information to the other personnel not in attendance. Ideas developed from the training and interaction with other individuals in the field are encouraged with the economic benefit to the organization as a method of evaluating the impact.
12.6.7 Variable Frequency Drives (VFD)

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

These units are generally equipped with a by-pass motor starter (conventional or electronic) to operate in the event of a failure of the normal variable speed drive. Additionally, providing a relatively cool and clean environment is necessary for proper operational life.

The installation or retrofitting costs are higher for this alternative and are recommended for challenging areas where the motors are greater than 75 HP and at wastewater pumping stations where a relatively steady flow is beneficial to the process.

At water pumping stations, this is the last alternative in areas where the power challenges are irresolvable.

The complexity of the electronics requires a higher level of training for its troubleshooting and repair. Many electronic technicians are leery of working on 480 volt power circuit devices. Also, these drives are more susceptible to power transients so transient surge suppression and grounding are vital.

Figure 12-17 – Mechanical Failure in Submersible Motor
12.6.8 Grounded versus Un-Grounded Electrical Systems

Most of the Water and Wastewater Pumping Stations are supplied by 480 volts, three phase, by the Guam Power Authority distribution system. These are connected either in a delta or a WYE configuration and either in a grounded or ungrounded condition. The predominant configuration being 480 volts, three phase, delta, ungrounded.

This configuration has several positive features such as 1) Operating the system with one of the phase legs grounded and 2) the ability to operate the station with only two of the three transformers in a bank.

This system, of course has its limitations being 1) Operating the system with one of its legs grounded which yield high fault currents when a second phase leg goes to ground, 2) the possibility of generating high, transient, over voltages to ground when in a single ground state.

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

Conversion from a Delta to a WYE transformer configuration involves engineering and coordination with GPA. GPA Engineering is requesting design plans, time to order the new transformer, and installation of the new bank. The system would also involve the revamping and replacement of the present electrical metering and wiring.

We recommend that all GWA stations (Water and Wastewater) be grounded as part of the grounding improvements at the facility. This is in line with the application of transient surge protection on the system.

12.6.9 Pump Operation and Control

At water pumping facilities, normal operation has been observed as 24/7. As the water system is improved, leaks identified and corrected, etc. the water level at the reservoirs will increase and eventually overflow.

A means to turn off the water well pumps is essential and would be covered by the SCADA system. Provision for interfacing for automatic control was observed to be installed in most of the stations.

At the wastewater pumping stations, only local and independent control was 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.

We recommend the investigation of these stations such that more consistent operation is achieved. In several stations, the reduced voltage starters did not engage. These need be corrected to protect the life of the motor and equipment.
12.6.9.1 Wastewater Pumping Stations

From observations at the wastewater pumping stations, a majority of the failures have been mechanical in nature. This is largely attributable to the frequent starting of the pump motor and the installation misalignment.

The larger pumps at stations like Southern Link, Route 16, and Mamajano experience frequent operation. Fujita station does also; however, continuous pumping was predominant. Southern Link’s 295 HP motor in particular experienced runs of less than 5 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 this station was observed at the motor shop. The root cause of the failure was the seal, allowing 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. This misalignment stress can cause small changes (in the tens of thousandths of an inch), sufficient to cause a seal to fail.

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 Electrician indicate that these sensors were not re-installed by the motor shop after a re-wind.

Also reported was the non-installation of this protective circuitry by the initial installation contractor.

We recommend that GWA Electrical staff personnel be involved in the inspection and acceptance of any new work involving an outside contractor and the testing of all protective circuits and controls.

12.6.9.2 Station Flooding (Dry Well)

Several wastewater pumping stations (4) were observed with flooded drywell conditions. This was largely due to a failure or a non-functioning sump pump. These stations were equipped with a submersible pump in the dry well.

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.

We recommend, as design criteria, 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 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 noted to be in relatively good condition. The driven equipment in the field such as motors, disconnect switches, etc. were noted to be damaged or in need of replacement.

New blowers were installed at Baza Gardens and the Agat Treatment Plant where the recorded power was less than the nameplate rating.

We recommend the installation of power factor correction capacitors with new installed equipment.

12.6.10 Partnering with Local Vendors and Repair Shops

Working with the local vendors and repair shops toward achieving excellence is the ultimate goal of a partnering program.

- Rewind motors or equipment to the voltage the end equipment would be using. An example is where a dual voltage motor wound for 230/460 volts, 9 leads, would be rewound to 460 volts, 3 leads. This will 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 need be tested for any errors in the winding process before it is dipped and varnished. The motor shop need be encouraged to obtain the equipment to perform this test, such as a surge comparison tester or motor analyzer, and warrant their work.

- The motor need be tested for operation before leaving the motor repair shop. All moisture and temperature sensor devices need be installed and tested with each submersible motor, per the manufacturer’s specifications. Any motor that has been repaired and will be placed into storage need 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.

- A full repair report need be prepared by the repair shop showing the work done, any as-found and as-corrected items noted, any machine work done with the machined measurements, etc. These data 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 to perform work. Motors that operate on a continuous basis are large consumers with savings in the range of a few percent, will reap large returns over the life the equipment. Such is the case of the deep well motors and aeration blowers.

Most of the facilities observed utilize the GPA Rate Schedule K (see Figure 10 below) as a basis for computing the energy costs. This rate schedule takes into account the energy consumed in kilowatt-hours and the measured demand. In this rate structure, no credit is offered for improved power factor correction. An Emergency Water Well and Wastewater Charge is also added to each kilowatt-hour of energy to handle the GPA operation and maintenance of GPA owned and operated generators.

As of this report, the total energy charged is approximately $0.17 per kilowatt-hour and include the Fuel Recovery Charge adjustment.
Figure 12-18 – GPA 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 - per kwhr $0.12905
First 200 kwhr per month - per kwhr $0.11421
Over 200 kwhr per month

Next 200 kwhr per kw of billing demand - per kwhr $0.09067
Over 400 kwhr per kw of billing demand - per kwhr $0.07104

Issued March 21, 1984
Revised October 01, 2000
Effective on October 01, 2000
Figure 12-18 – GPA Rate Schedule K (continued)

SCHEDULE "K" (Continued)

For Three Phase Service:
First 200 kwhr per kw of billing demand  - per kwhr $0.14932
First 400 kwhr per month  - per kwhr $0.11413
Over 400 kwhr per month

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 $0.00145 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.
Figure 12-18 GPA Rate Schedule K (continued)

<table>
<thead>
<tr>
<th>Issued March 21, 1984</th>
<th>Rate Schedule &quot;K&quot;</th>
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<td>Revised October 01, 2000</td>
<td>Effective on October 01, 2000</td>
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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

An example of energy savings is the case for Station Y-15.

During August of 2005, this station consumed 75,200 kilowatt-hours (KWH) of energy with a demand of 112.8 kilowatts. At $0.17 per KWH, this would amount 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 less 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 3800 KWH could be realized. At $0.17 per KWH, this would equate to $646 per month or $7,752 per year. This would be one of the bases for improving the electrical system to each well in addition to the cost savings due to improved operation with less motor failures.

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

The implementation and execution of this plan is imperative for the successful electrical operation and maintenance of the GWA facilities. See the Recommendation section for details of each area.

The following are steps to implementing this plan:

1. Obtain updated voltage, current, and power data at each station along with three day recordings (minimum). This information will be used in conjunction with the recordings developed over the past year and provide a second reference point of information.

2. Correct the Voltage Unbalance at all Stations to within 1%. This will require GPA to balance the distribution line circuits for these stations with a priority for those critical northern and central water wells. At the same time, replace any damaged lightning arrestors and protectors, improve grounding, reconnect transformer secondary conductor (to minimize water entry), and replace conductors (to 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.

3. Install voltage unbalance relays at the auto transfer switches. This 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 the motor size and loading, to determine the in place safety factor. The target setting would be between 1 and 2%.

4. Install Franklin Electric Sub-Monitors for all deep well motors and improved motor circuit protectors for all other motors with duty cycles greater than three hours per operation. This will serve as the primary protection of the electrical equipment.

5. Improve the station grounding to the well shaft. Tie into the GPA power pole and meter ground. Bend metal where electrical installed.

6. Install Transient Surge Protection (TVSS) at the service main disconnect at all Stations.

7. Correct water entry into the pumping stations. This is a high priority safety item and can be completed concurrently with the other steps.

8. Implement GPA owning and maintaining all standby generators and auto transfer switches.

9. The replaced operational deep well phase monitors can be used at other wastewater and water treatment facilities, where not installed, to augment the protection scheme already in place or become a source of spare parts.

10. Reactivate and install the SCADA system to monitor equipment operating status.

11. Conduct a power factor correction study and install correction capacitors where beneficial.

12. Install variable frequency drives at selected waste water pumping stations to improve the process flow.

13. Initiate design plans to convert the electrical system at each station to a grounded service.

14. Train personnel at every opportunity in all aspects of theory, principles of operation, installation practices, and troubleshooting and maintenance.

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“This is a draft report and is not intended to be a final representation of the work done or recommendations made by Brown and Caldwell. It should not be relied upon; consult the final report.”

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12.7.1 Electrical Testing Procedure for Deep Well Motors

1. 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.

2. The unbalance voltage and current should be computed by the Data Recorder using the phasor diagram setting. Check to insure that the phase rotation is correct before beginning the recording session.

3. Begin Recording and take a snapshot of the waveform while on GPA power. Record for approximately 10 minutes.

4. Turn Station Main Breaker “OFF”. This will remove power to the station and start the emergency generator after a time delay. Note the time delay period between power off and generator start.

5. After the transfer switch transfers and the well pump motor starts, take another snapshot after the well water either pumps through the by-pass valve (if applicable) and again when pumping into the main line.

6. Operate the pump on the generator for at least 15 minutes. Note any abnormal sounds from the generator.

7. Turn the Main Breaker “ON”. Note the time delay period from when the breaker is turned ON to when the transfer switch transfers back to normal power.

8. Take another snapshot after the return to GPA Power.

9. Note the time after the transfer switch return to Normal and when the generator is shut down (Cool down period).

10. All times and readings should be recorded in a standard test form for future reference.

11. Download the recorded data for analysis and in particular the following conditions:

   - Unbalance Voltage and Current Condition (IEEE Method is okay) 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 the source of the unbalance is GPA. If there is improvement but not substantial then the source

“This is a draft report and is not intended to be a final representation of the work done or recommendations made by Brown and Caldwell. It should not be relied upon; consult the final report.”
Electrical Practice Procedure for New Motor Installation

1. Determine root cause failure for previous motor. This information to be recorded and stored with the station file and include digital photos of the exterior and interior, measurements, description of the symptoms and corrective action, etc.

2. Check motor starter connections. Torque connectors at breaker, motor starter, motor overload, and disconnect switch at motor (if available). Torque to be per the manufacturer recommendations.

3. Inspect motor starter contacts for contact wear area and condition. Use contact burnishing tool to smooth any rough areas. Check alignment for improve contact area.

4. For deep well motors, terminate the motor leads with power cable using hydraulic crimper and proper applicable barrel crimp. Encapsulate the terminations and allow to cure.

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

Insulate the termination as follows, after the motor rotation has been determined using the motor tester:

- 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)

5. Check voltage prior to starting. Record photo to identify manner of ground condition.

6. Test motor for phase rotation. For non-submersible motor, test motor rotation and phase rotation before connecting (see item 4 above).

7. Check motor and controls for proper operation. Check control and timing relays for by-pass valve operation.

8. 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%, contact GPA to balance transformer voltage before repeating step 8.
9. Record motor data in maintenance records and apply motor nameplate label at the motor starter cabinet. Place label over the existing label. Date the installation on the label.

10. 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.

11. Record station for three days and analyze information for any voltage and current anomalies. Coordinate with GPA, as needed.