Determining Power Quality and Reliability Criteria for Ultraviolet Disinfection in Drinking Water Facilities

Data Bulletin

8000DB1201
November 1, 2012

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Introduction

There are many benefits in using Ultraviolet (UV) light instead of, or to augment, chlorine disinfection in many drinking water facilities. However, UV treatment presents some unique power challenges not faced by other processes in drinking water treatment. This document focuses on the power concerns of UV applications.

Because of this power focus, this document is primarily intended for the design of the electrical system feeding UV applications. Some material has been added throughout this note and its appendices for facility management and operations personnel. This document is not intended to help determine when a UV system should be used, how it should be sized nor how it should be configured.

EPA Regulations

The United States Environmental Protection Agency (EPA) is interested in protecting people that have their water provided by Public Water Systems (PWS). The EPA defines a PWS as having at least fifteen connections, or serves at least 25 people for at least 60 days, and delivers its water through canals, pipes and other constructed means[1].

The EPA has detailed its requirements for UV applications in the *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule* (UV Disinfection Guidance Manual). This manual requires the following from PWSs:

> *"To receive disinfection credit for UV, both filtered and unfiltered PWSs must treat at least 95 percent of the water delivered to the public during each month by UV reactors operating within validated conditions for the required UV dose."*[2]

This means that 5% of the monthly flow can be outside of the EPA required specifications for UV dosage. Any water that does not meet the EPA required UV dose specification is called "Off-Specification"[3]. This Off-Specification can occur for a variety of reasons including a reduced dose of UV, a complete power outage, or a flow rate greater then the UV system's certification[4].

As long as the total Off-Specification flow is under 5% of total monthly flow, then the facility is in compliance with the EPA. This 5% allowance equates to a full day and a half of flow (assuming a 30-day month and equal flow each day). For the purposes of this application note, we will refer to this 5% monthly allowance as the "Off-Spec Allowance".

The "Off-Spec Allowance Power Philosophy"

Based on evidence from an informal poll, interviews with UV suppliers, and visits to actual facilities, there is a perception that the "Off-Spec Allowance" negates the need to worry about power quality and power reliability in UV systems. The rationale is that if power cannot be restored in the 1.5 days allowed, then there are worse problems than UV compliance. While this "Off-Spec Allowance Power Philosophy" makes sense, a closer look reveals five challenges to this concept. The five challenges are:

1. UV Lamps-On Requirement During Treatment
2. Local Regulations
3. Maintenance
4. Validation and Re-Validation
5. Equipment Life

Each of these challenges has technical details that are critical to a full understanding of proper power design on the UV application. This information is located in Appendices A and B. We recommend that these appendices be read as part of this data bulletin.

UV Lamps-On Requirement During Treatment

The first challenge to the "Off-Spec Allowance Power Philosophy" is in the same paragraph that requires that 95% of the monthly flow must be treated. The end of this paragraph says:

> *"For purposes of design and operation, PWSs should strive to deliver the required UV dose at all times during treatment."*[5]

Thus, if treatment is occurring, then the lamps must stay on and at the proper dose. By extension, power disruptions during treatment cannot be allowed to extinguish any of the lamps within a reactor. Especially when it can take 10 minutes to restore the lamps for each outage (See Appendix A). Power quality and power reliability issues can be predicted during design and mitigated during operation. Because of this, the "Off-Spec Allowance Power Philosophy" cannot be applied here.

Local Regulations

The second challenge, which relates to the above challenge, is in regards to local regulations. These regulations may restrict or eliminate the EPA "Off-Spec Allowance." The January 2012 issue of *OpFlow Magazine* had this to say about local regulations.

> *"…most regulators require a treatment goal of no Off-Specification water, but allow Off-Specification water (1-5 percent) if unusual or emergency conditions occur. The production of Off-Specification water can't be purposeful…"*[6]

It is clear from the UV Disinfection Guidance Manual, and *OpFlow*'s quotation that the intent of the regulations is to prevent any type of Off-Specification event that can be predicted or prevented. Power quality, power reliability and maintenance needs can be predicted and prevented. Thus they must be addressed and cannot rely on the "Off-Spec Allowance Power Philosophy."

Maintenance

Maintenance, the third challenge, is an activity that is clearly part of normal plant operation. The *UV Disinfection Guidance Manual* states the following in regards to maintenance.

> *"The power to the lamps is typically delivered through individual GFI circuit breakers and ballasts. The GFI breakers should be test-tripped at least once per year and should be maintained in accordance with the manufacturer's recommendations."*[7]

This clause demonstrates that the EPA's intent is to ensure that electrical circuit protection to each UV Lamp is confirmed.

What is surprising is that the *UV Disinfection Guidance Manual* does not have any requirement for the circuit breakers feeding the UV reactors or system. After all, the feeder breakers or fuses carry power for more than just a single lamp, and thus can have a greater impact on the system.

Therefore, even though it is not specifically mentioned in the *UV Disinfection Guidance Manual*, the feeder breakers or fuses must also be properly maintained to assure system integrity.

The challenge is that traditional breaker and fuse maintenance activities require power to be disconnected. This means shutting down at least part of the UV system, if not the entire system.

At first glance, it might be reasonable to apply the "Off-Spec Allowance Power Philosophy" to this activity. Yet this philosophy does not comply with the requirement to keep the lamps on at the proper dose during treatment[8]. From this, you could deduce that maintenance of a UV system can impact the treatment rate. Let's examine this further.

Many facilities have multiple UV reactors, and possibly a spare. For these facilities, each reactor may have a dedicated circuit breaker. Thus, it is possible in most instances to perform maintenance on a single train at a time by opening that breaker. These dedicated breakers, and the reactors they serve, will be grouped together and fed by a single larger breaker. To perform maintenance on this larger breaker will require shutdown of the UV system, and thus will shutdown the treatment process (See Figure 1).

Another alternative is to put part of the UV system on a separate power feed, perhaps on the facility generator side (See Figure 2). This means that half of the UV system is fed from a power utility, and half is fed from an onsite generator. During normal operation, power from the power utility is provided to the generator side of the system via a tie breaker. During maintenance of the power utility fed side breakers, this tie breaker will be open and the generator will be on. Thus, only the power utility half of the UV system will be down. The generator side will still be on-line. Likewise, if we maintained the generator side, the tie breaker would be open and only the part fed by the power utility would be powered. If we assume that full flow requires all four reactors shown in Figure 2, then a 50% reduction in UV capacity will halve the facilities maximum output.

Of course, other facilities may have a single reactor, or multiple reactors fed from a common power supply cabinet. For these facilities, shutdown of that reactor, or common power supply cabinet, will result in shutdown of the entire process.

Regardless of which scenario a specific utility falls into, maintenance may require careful coordination with the needs of the water distribution system, or a method to keep the UV lamps on during maintenance activities.

Validation and Re-Validation

The fourth challenge focuses on the requirement for validation and re-validation. Validation confirms that the UV dosage delivered to the water is sufficient to disinfect the contaminants. The *UV Disinfection Guidance Manual* requires each installed UV system to be validated[9]. The *UV Disinfection Guidance Manual* also indicates that there are times when revalidation is required. These include changes to the reactors such as changing lamps, or changes to the ballasts. There are two requirements that need to be considered. The first one is:

> *"Modifications to lamp ballasts include changing the operating voltage, current, frequency, and waveform."*[10]

Just to clarify, the *UV Disinfection Guidance Manual* says that any change to the electrical input to the ballasts can change the ballast performance and is considered a modification to the ballast itself. The second requirement is:

> *"Changes that will modify the UV output so that emitted intensity is uneven along the length of the lamp or around its circumference."*[11]

Power quality, especially voltage sags, swells, and harmonics, can change the electrical waveform to the UV system. This includes both the ballasts and the lamps themselves. Thus, in theory, waveform distortion in a UV system could lead to revalidation.

In practice, this probably won't happen. UV Transmittance (UVT) sensors in a reactor regulate dosage. If power quality changes the UVT, then more lamps may be activated to compensate for the change. This automatic action will most likely negate the need to revalidate. But, adding intensity exposes more lamps and ballasts to the damaging impacts of power quality problems, and could lead to decreased lamp and ballast lifetimes.

Yet, it should be noted that a change in power quality may first reveal itself as an unexplained increase in power usage. By conducting careful power monitoring, you may reveal a change in power quality before lamp and ballast lifetimes are impacted.

A change in power quality at a facility can occur after validation if equipment is added or modified at a facility. While storms can impact quality, these are short duration and temporary. Of greater concern are long term contributors to power quality. This is usually, from adding, or modifying, pumps, blowers, VFDs, data servers, ozone systems, or other types of electrical equipment. Furthermore, since the facility is connected to a power utility, it is possible that changes at off-site facilities can lead to a change in system performance.[A]

To prevent this, a power quality corrective system should also be installed. This is discussed below.

Equipment Life

The final challenge is not regulatory in nature, rather it is engineering-oriented. Power quality problems can have a dramatic impact on the life expectancy of equipment.

Appendix A provides a technical analysis of power quality in facilities. The appendix references actual plant studies. These were of short term duration of just a few days[12], and long term duration of between 5 to 13 months[13]. None of these studies were long enough to assess the impact that power quality has on equipment life of UV systems.

Power quality issues can shorten the life of lamps and ballasts. To offset this risk, a PWS may install redundant UV reactors.

Power quality can also impact the life of equipment such as breakers, fuses, bus joints, switchgear, and transformers. “Effects can range from spurious operation of equipment to a failure of important plant equipment, such as a machine or transformers.”[14] Many of these systems are upstream from the UV system, and may not have redundant units available. If the intended lifetimes of these systems are impacted by harmonics, then it can take more than 1.5 days to get power restored.

For example, large transformers are manufactured on demand, and are not stocked in a warehouse. If a transformer needs to be replaced, then it can take days or weeks until a new one is manufactured. During this time, it may be difficult to keep the UV system powered.

Power utilities understand the issue of power quality, and how it can impact reliability. This is why IEEE 519 exists. IEEE 519 is a power quality standard that requires any commercial or industrial facility to have their harmonics loading eliminated at the point where the facility connects to the utility.

While this sounds simple, actual implementation may require a multi-level approach. Square D, a brand of Schneider Electric, has an excellent paper written on this topic. This paper, titled *Ultraviolet and Ozone Disinfection Electrical Application Guide*, was written by Jim Codling in September 2008.

UV Power Solutions

The preceding text, and Appendices A and B, details the power quality, power reliability, and the technical challenges that exist in a UV system.

Understanding these requirements and understanding what solutions are available are two different things. This section discusses the solution requirements, some sample solutions, and the relevant technology.

[A] IEEE 519 should prevent this from occurring. If IEEE 519 is overlooked, or misapplied, then harmonic issues can occur. If this happens, it can be difficult to determine which utility customer is in violation of IEEE 519, and harder to hold them accountable for any damages at the water facility.

The *UV Disinfection Guidance Manual* has guidelines detailing how a power system should be designed in a facility. Nevertheless, the "Off-Spec Allowance Power Philosophy" sometimes has erroneously trumped these guidelines.

Many drinking water facilities have on-site backup generators in case of utility power failure. These systems are actuated either manually or automatically and a small power loss happens while the transfer occurs. Traditional technologies used in drinking water facilities are tolerant of momentary power loss and this system has worked well. But, the dynamics of UV systems, and the requirements of the *UV Disinfection Guidance Manual*[15] point to a more robust type of power redundancy system.

For that reason, we need to discuss the power reliability requirements and what solutions can be adopted.

Electric System Design Guidelines

The *UV Disinfection Guidance Manual* discusses power quality in a variety of places. By studying the document, the following requirements become clear.

1. Voltage sags cannot be more than 10% of the nominal voltage for more than 0.5 cycles (8.3 milliseconds)[16].
2. All lamps required to maintain validation must be on to prevent an Off-Specification event[17].
3. All replaced or repaired UV equipment must be of equal or better quality to those used during validation[18]. As we know, UV system reliability is a combination of the UV system itself and the reliability of the power feeding it. Thus, this section should be extended to the electrical system since it can impact reliability and validation.
4. Must meet IEEE 519 as a minimum[19].
5. Ballasts must be powered by a grounded source[20].
6. Proper grounding must be assured for the entire system[21].
7. GFI breakers must be used on lamps[22].
8. Provision for electrical lockout at each UV reactor[23].
9. If installed, power meters must be able to measure true power, not just kVA[24].

UV Application Categories

UV applications are varied based on flow, power, water quality and other requirements. A complete breakdown of all types is not possible. But we can divide these applications into three broad categories. These are:

Conventional Treatment

Most PWSs use a conventional treatment method. These systems depend on gravity for flow through sedimentation beds and gravity filters. In these systems flow, and by extension treatment, can occur even if power is off. Thus, the UV lamps must be on until flow stops. Because of the inherent retention in a plant, it may take a while before flow actually stops at the UV reactor.

For these systems, an Uninterruptable Power Supply (UPS) offers several advantages. UPS systems should be sized to handle the longest of three different criteria. These are listed below under the UPS section. Also, a full harmonic system, and transient voltage surge suppression needs to be addressed. This is because other facility loads, such as a VFD, may impact the power quality that is entering the UPS, or of course at the point of common coupling as defined in IEEE 519.

Figure 1 shows a medium voltage (<15 KV) facility with low voltage (<600 Vac) three phase power with the UV system on the generator side of the medium voltage switchgear. In this system the UV is placed on the generator side of the switchgear to protect against an inoperable tie-breaker.

A variant to Figure 1 is shown in Figure 2. This variant splits the load. If this is the case, then half of the facility load, including half of the UV reactors would be on the main side, and half on the generator side. The UPS would be primarily needed to insure the lamps stay on during a power transfer[B].

This variant could have full reactor redundancy on both the main and generator side. This configuration would assure full flow during maintenance. Yet, it will probably be cost prohibitive to have twice the number of reactors, associated piping, valves, and floor space than required to handle the flow. Another aspect of this variant becomes apparent if automatic controls are used to activate and deactivate the UV reactors. If this is the case, then this variant can be more complicated because the control system needs to know which reactors are available to be activated. This would mean power and breaker position monitoring.

The preceding two paragraphs are based on the assumption that control of the utility feed (also known as main), tie, and generator breakers are controlled automatically. Many times the control of these breakers is a manual operation. If power is lost when the facility is unmanned, then changeover time includes the time needed for an operator to arrive on site. This may have an impact on the size of the UPS[C]. Also, this may impact how the UV system is controlled, and impact the control system design or sequence of operation for the entire facility.

Figure 3 is for a three phase low voltage (<600 Vac) power and UPS configuration. This design shows a dual input UPS with one input on the main side of the switchgear, and the other on the generator side. This provides redundancy and the ability to maintain the main and generator breaker without taking the whole system offline.

Finally, Figure 4 is the same as Figure 3 except that the UPS side is 120 Vac, and harmonic transformers are used to mitigate the UPS harmonic loading. The power correction system (PCS) is only shown because of its use on the <600 Vac motor loads in the system.

Package Plants

Package plants are basically self contained treatment systems, or portions of systems. The variety of package plants and their applications is immense. Some might be portable treatment trailers with their own self contained power generation systems for emergency or temporary water supply. Others might be embedded into a full scale treatment plant. Package plants can have a variety of upstream pumps, valves, or other equipment that will prohibit flow once power is off. For this paper, we will only be discussing package plants that are complete systems. These can be subcategorized into **Mainline Treatment**, and **Temporary Treatment**.

A **Mainline Treatment** package plant system is a community's primary drinking water treatment system. While these are small, they may still be considered PWS if the system has at least 15 connections or regularly serves at least 25 people[25]. If a mainline treatment package plant is a PWS, then all of the requirements of the UV Disinfection Guidance Manual must be satisfied. For these applications, either Figure 5 or Figure 6 might provide some guidance on the proper method of power system design.

Some package plants can take several minutes to restart. Thus, power related restarts will quickly become frustrating to operators. For these systems, Figure 5 might be the best solution. This solution has the UPS sized for the UV system, motor loads, and other loads. This will minimize restarts by providing power during momentary power losses and voltage sags.

B See the section on UPS sizing for more information.

C See the section on UPS sizing for more information.

Likewise, some package systems are more tolerant of power loss or voltage sags. For these, Figure 6 might be a valid solution. Figure 6 only has the UV portion on the UPS. This solution will keep the lamps on and help to meet the *UV Disinfection Guidance Manual*'s lamp on requirement[26].

A **Temporary Treatment** package plant is usually brought in to provide water in case of main facility failure, to augment in case of a natural disaster, or to provide water during a temporary event. But what are the requirements for these systems?

A Temporary Treatment package plant might still be considered a PWS if it is connected to 15 or more connections, or serves at least 25 people for at least 60 days[27]. If this is the case, then it may require adaption of the site wiring, or possibly using the solutions proposed in Figures 5 and 6.

If the Temporary Treatment package plant does not meet the definition of a PWS, then this is truly temporary, and the UV Disinfection Guidance Manuals requirement to keep the lamps on full time during treatment is not required. This has a large impact on the design of the power system for these facilities. Still these systems need to operate reliably. Furthermore, they may be powered by temporary community generators, or by a power utility that is operating at a reduced level of reliability or power quality. For this reason, some form of power compensation capability may still be desired.

An in-depth analysis of these non-PWS Temporary Treatment package plants may reveal that Figure 5 and 6 below are your best options. However, Figure 7 illustrates the use of a Sag Ride-Through Conditioner (SRTC). A SRTC is used to stabilize the voltage entering the package plant. A SRTC needs some form of input power to operate, thus it does not provide true backup like a UPS. Yet, it can prevent system restarts, or lamp outages during the types of voltage sags you can expect from community generators, or unreliable utility power.

Membrane Treatment

Membrane treatment systems can be thought of as a cross between conventional treatment and package plants. Membrane based facilities require a differential pressure across the membranes to provide treatment where as a conventional treatment system relies on gravity.

Membrane treatment, like packaged plants, are often supplied on multiple skids with self-contained pumps for treatment, backwash, etc. These modules will be brought online, backwashed, or put in standby as needed. Thus, these systems will have more pump starts and valve cycles than conventional treatment, and steps need to be taken to insure that harmonics and surges are handled properly. Like package plants, the membranes system must be interlocked so that the UV lamps are on before the membrane system is allowed to start and that they stay on until flow stops.

Membrane treatment systems are oftentimes used in place of conventional gravity filters or, in some cases, the sedimentation basins. For these types of systems, the UV is often not part of the membrane skid, but rather a separate process. Because of this, the UV system will may need an appropriately sized UPS.

If the UV reactor is coupled with the membrane treatment skid, then it is possible that a UPS is not required. That is because the skid's flow may decrease rapidly enough on a power loss that the UV power supplies may be able to keep the lamps on until flow stops, or until a skid effluent valve closes.

Power Solution Layouts

The preceding section talked about the different application categories. This section will illustrate some of the different power configurations that can be used. These diagrams are to be used for illustrative purposes only, and not as fully engineered solutions. As such, some technologies, such as power meters, lockout equipment, and individual lamp GFI breakers are not shown. The following diagrams will be divided into the respective UV application categories: Conventional Treatment, Package Plants, and Membrane Treatment.

Conventional Treatment

Figures 1–4 are intended to show a voltage-based system, not a power-based system: Thus a few items need to be mentioned:

- The bypass is always shown outside the UPS. Yet, some UPSs may have integrated bypass switches.
- The automation system should be programmed so that the UV lamps are on before start up. This will help to minimize Off-Specification time.
- The main and generator transfer is shown as an automatic breaker switching system. An Automatic Transfer Switch can be used also.
- Where relevant, dual input UPSs are shown with interlocked upstream circuit breakers. A single input UPS can be adapted to dual inputs as shown in Figure 10.
- The UV reactors are each shown connected to the UPS through a panelboard. For simplicity, the UV reactor ballast cabinet is not shown. Depending on the UV manufacturer, the ballast panels may have a single feed point, and divide the power internally to the reactors. If this is the case, the panelboard may not be needed.
- The PCS in Figure 4 is only for the <600 Vac motor loads in the plant.
- The UPS system illustrated in Figure 4 is explained in Figure 9.

Figure 1: Medium Voltage Distribution with Low Voltage (<600 Vac) UV

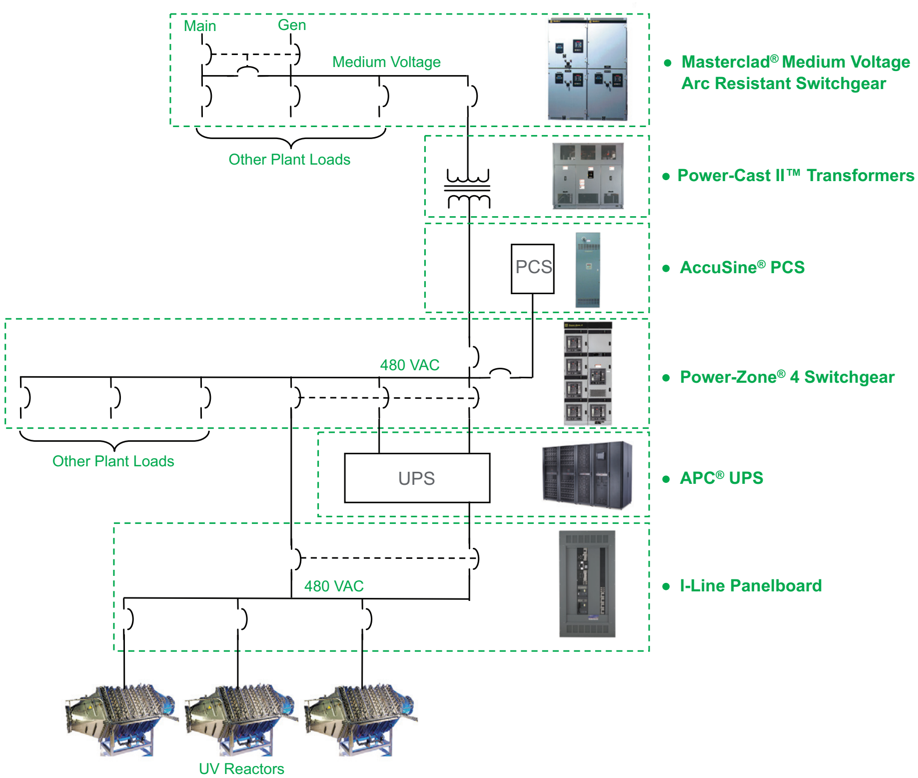


Figure 2: Split Medium Voltage Distribution with Low Voltage (<600 Vac) UV

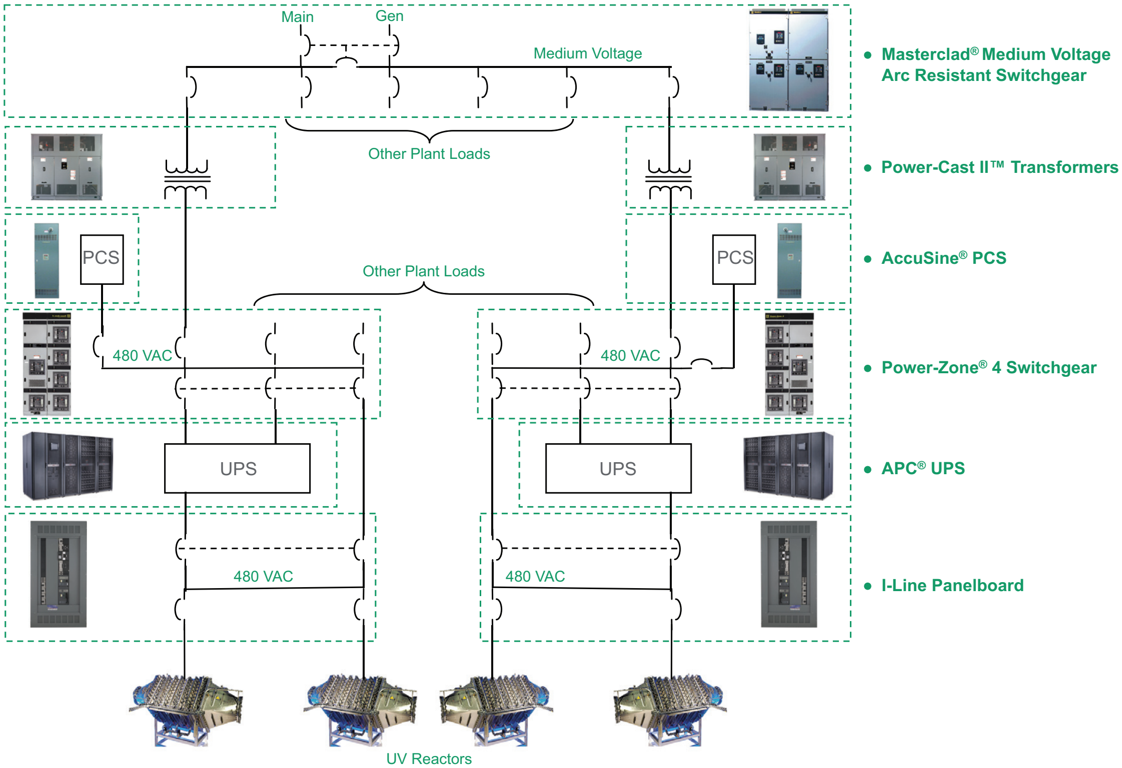


Figure 3: Low Voltage (<600 Vac) Distribution and UV

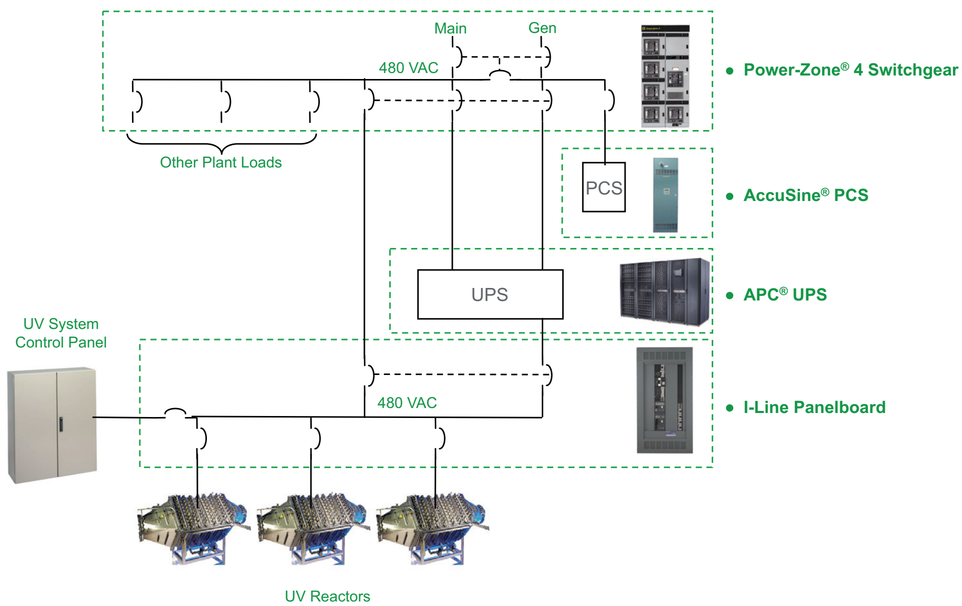
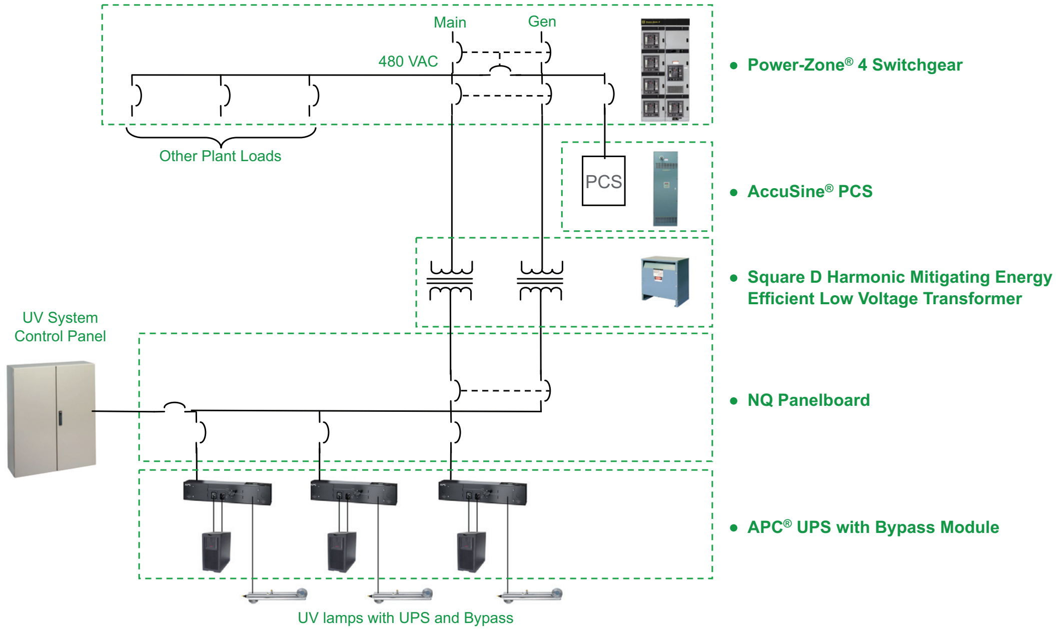


Figure 4: Low Voltage (<600 Vac) with 120 Vac UV systems



Package Plants

Figures 5–7 show a typical package plant where the plant has a custom electrical panel that houses the starters and automation for the package plant. In this system, the UV is integral to the package plant system. For those systems where the UV is separate from the package, then this is similar to Figures 1–4. A few items need to be mentioned:

- Figure 5 is sized for the UV and motor loads. This will help maximize system up time.
- The automation system should be programmed so that the UV lamps are on before start up. This will help to minimize Off-Specification time.
- Figures 5 and 6 show a main and generator transfer is shown as an automatic breaker switching system. An Automatic Transfer Switch can be used also.
- Figure 7 does not show a backup power supply. This is because these systems are temporary in nature.
- Another alternative for Figure 7 is to put one SRTC above the I-Line. However, this may impact how the generator and main are connected.

Figure 5: Mainline Treatment Package Plant with full UPS backup

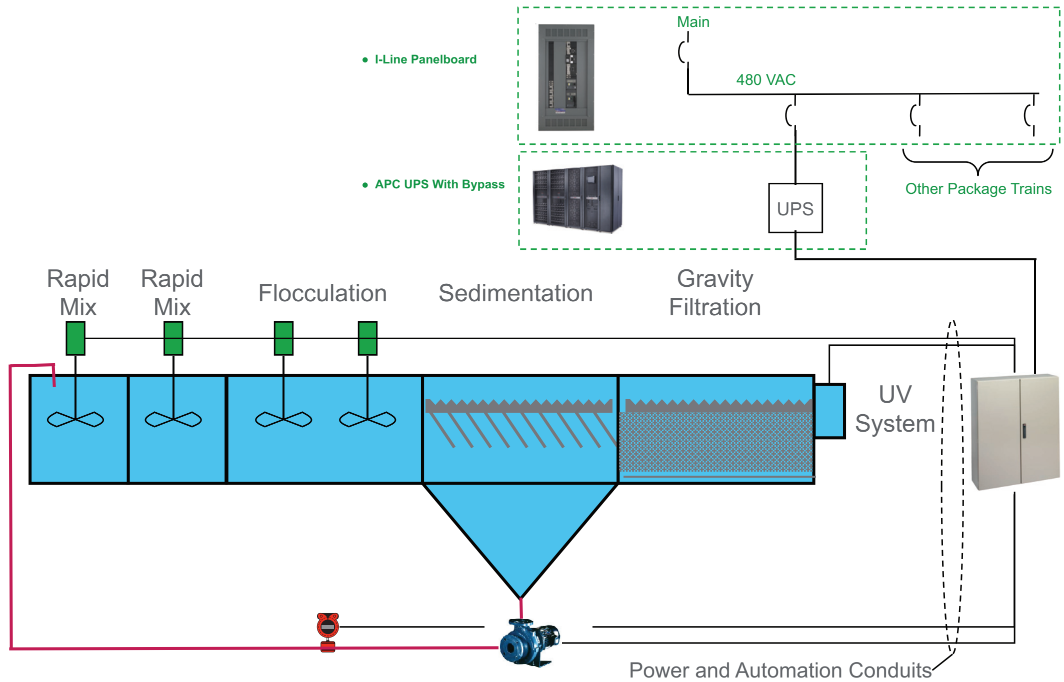


Figure 6: Low Voltage (<600 Vac) Package Plant with UPS for UV Only

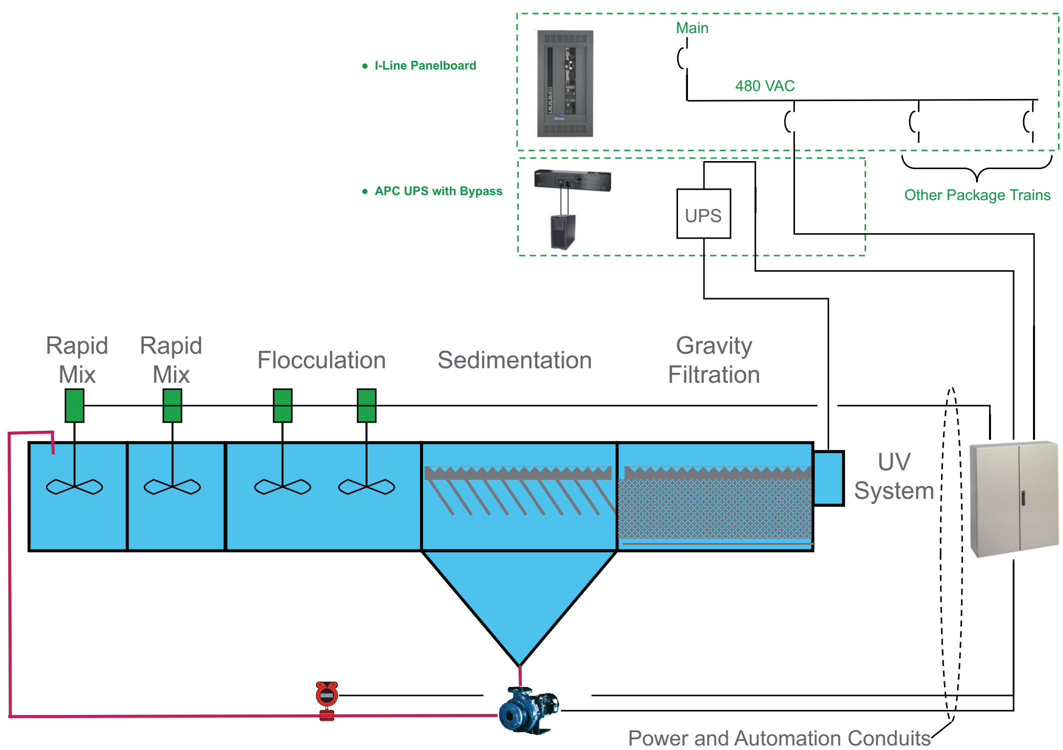
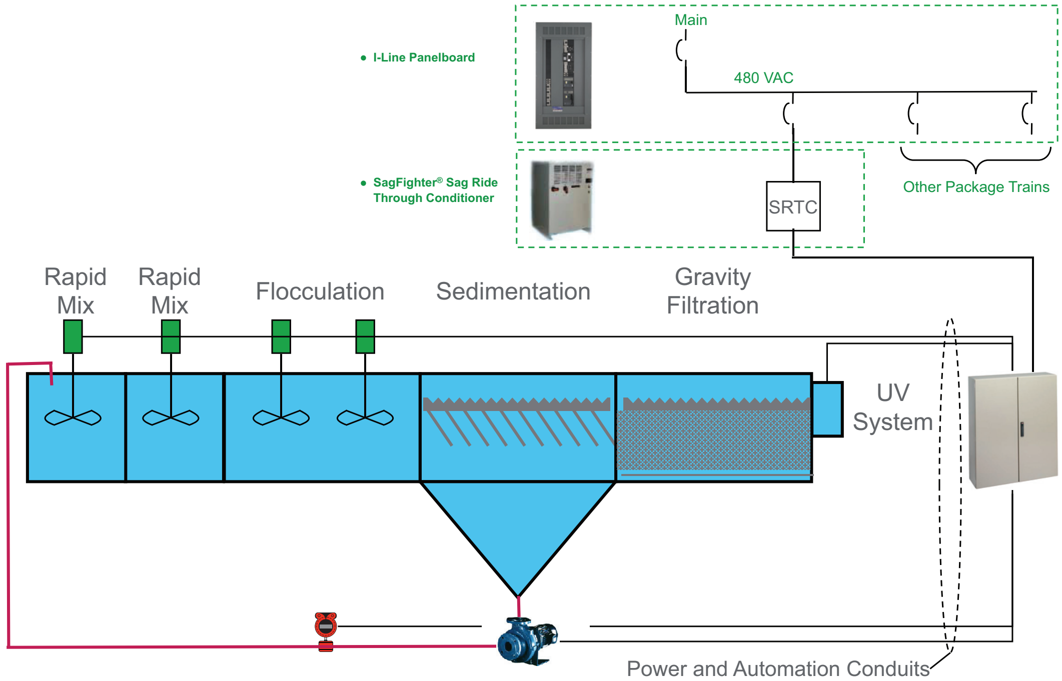


Figure 7: Low Voltage (<600 Vac) Temporary Package Plant with SRTC

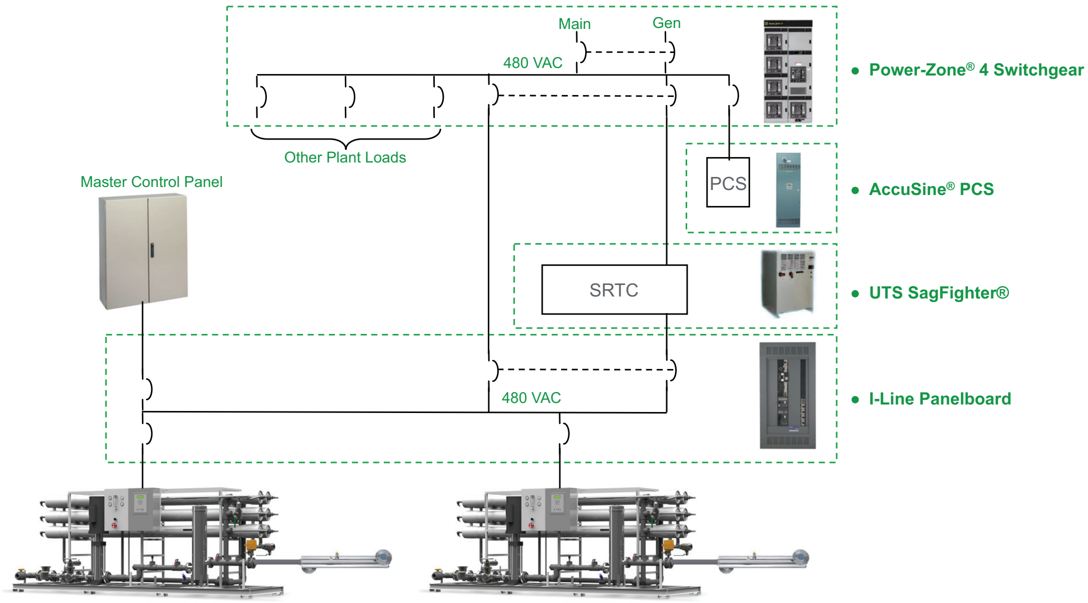


Membrane Treatment

Figure 8 shows a typical membrane system where the UV is integral to the skid. Each skid has a custom electrical panel that houses the starters and automation for the skid. For those systems where the UV is separate from the skid, then the UV system layout is similar to Figures 1–3. A few items need to be mentioned:

- The SRTC is sized for the entire skid-mounted system. This will help maximize system uptime by minimizing sags.
- The automation system should be programmed so that the UV lamps are on before start up. This will help to minimize Off-Specification time.
- The main and generator transfer is shown as an automatic breaker switching system. An Automatic Transfer Switch can be used also.
- Another alternative is to have a dedicated SRTC for each skid.

Figure 8: Membrane with dedicated UV system



Membrane Skids with integral UV Reactor and local control panel

Power Equipment For UV Solutions

Power distribution systems are comprised of a variety of different types of devices. Some of these have an impact on the UV application, others do not. The following discusses three different types of devices, UPSs, Harmonic Mitigation Equipment, and SRTCs.

Uninterruptable Power Supplies

As we have stated, there are times when a UPS is required for UV applications. A UPS offers several advantages in a UV application. All of these advantages keep a utility in compliance with the design and operation statement of the *UV Disinfection Guidance Manual*[28].

Sizing of the UPS is critical. There are two criteria needed to size a UPS. You need to look at both the watts and the VA. The watts will tell you the total power that needs to be drawn from the UPS, and the VA will tell you how much current can be delivered. Of course, this means that a proper understanding of the power factor of the UV application is desired. To get this information, you will need to contact the UV system supplier. If there is still confusion regarding power rating or power factor, choosing a UPS with a watts rating that is equal to or greater than the VA rating of the load, will always ensure a safety margin[29].

When determining the wattage and VA rating, it is important to realize that the UPS system will serve up to three purposes. The UPS and its batteries should be sized for the most time-intensive of the three. These three purposes are:

- Maintaining power during power transfer (Transfer Time)
- Keeping the system online until flow stops during shutdown (Shutdown Time)
- Keeping the UV lamps on during breaker removal or routine maintenance (Maintenance Time)

Voltage sag is not typically a criterion for sizing since the sags are typically momentary, and thus covered by the other criteria.

There is one other consideration when determining Transfer Time, Shutdown Time, and Maintenance Time. As process equipment ages, it can take longer to react to changes. Since drinking water facilities can go twenty years or more between upgrades, it would be wise to add a safety factor to these times to account for aging equipment.

UPS systems in UV applications are surprisingly varied. This is because different types of UV systems require different types of power. They can range from 120 Vac single-phase systems to 600 Vac three-phase systems. Since the applications are varied, then it should be no surprise that the methodology for their application is equally varied. However, there are some basic concepts to consider regardless of the type of UPS.

The first concept is some kind of bypass. For single-phase systems less then 16 kVa, a bypass unit can be purchased that will allow for removal and replacement of the UPS while keeping the UV lamps on. This is shown in Figure 9.

Figure 9: Single-phase bypass for UPS systems

For larger systems, a bypass can be made using interlocked breakers. Furthermore, some of the largest systems have bypass switches that are either part of the UPS system, or integral with the UPS itself.

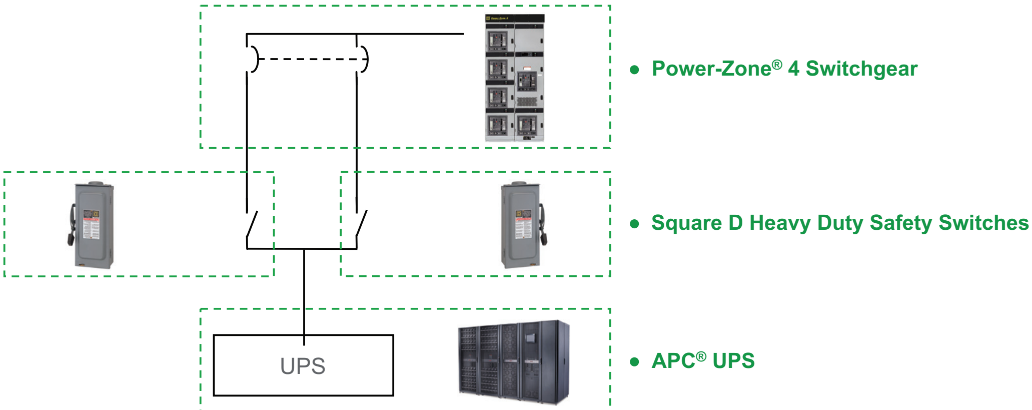
As mentioned above, the UPS needs to be sized around three criteria, including Maintenance Time. If Maintenance Time is the ruling criterion for UPS size, then two methods exists to make the UPS smaller.

The first answer is additional batteries. Many UPSs can be purchased with additional batteries. These batteries will not modify the rating of the UPS, but will provide additional time before shutdown.

For instance, your application might require 2.95 KW for 25 minutes to satisfy the maintenance requirement. The supplier's catalog may have a 3.0 KW unit rated for 15 minutes. Instead of upsizing the UPS, it may be possible to buy additional batteries and extend the backup time to 30 minutes. Of course, there comes a time when the cost of additional batteries makes this solution unattractive. When this occurs, the second answer offers a solution.

The second answer is a dual feed UPS system. This can be accomplished in two ways. One way is to use a dual feed UPS. The other way is illustrated in Figure 10.

Figure 10: Dual Feed to a Single Feed UPS



UPSs come in a variety of types. Table 1 summarizes these types, and provides a guide on which technologies are suitable for UV. For a more in-depth discussion on the different types of UPSs, please see Schneider Electric's Data Center Science Center White Paper #1, *The Different Types of UPS Systems*.

Table 1: UPS types and applicability guide[30]

Type	Description	Advantages	Disadvantages	Notes	Range	UV Applicability
Standby	Source power is directly fed to the load and the battery is charged in parallel. When the incoming power disappears, the load is transferred to the batteries	• Low cost • Small footprint • High efficiency	• Transfer time can take up to 25 ms[31] (10 ms for APC units)	Power loss as little as 0.5 cycles (8 ms) can shut off the lamps[32].	< 0.5 kVa	Not recommended since transfer time can lead to lamp extinguishment. Requires careful coordination with UV suppliers' tolerance to power loss over the lifetime of the system.
On-Line Interactive	Battery to AC inventor is always connected to the UPS output. When source power is present, this inverter charges the battery	• Less transients than Standby • Voltage regulation	• APC has maximum transfer of 8 ms		< 5 kVa	
Standby - Ferro	Similar to a standby system. The difference is that this unit has a large Ferro transformer. The discharge of this transformer provides the output power during transfer	• Eliminates transfer time • Can provide some voltage stability	• High heat • Large and heavy • Can interfere with proper operation of some UV systems	Pseudo on-line system	3–15 kVa	Ability to hold up power, and provide voltage stability is good in some UV applications. Care must be taken since some UV suppliers use ferrous transformer in their power supply. If this is the case, then this UPS cannot be used.
Double Conversion On-Line	All power is converted to DC, and then all DC converted back to AC. Batteries are connected to DC bus	• No transfer time. • Near ideal power output	• Non-linear nature can interfere with generators. • Greater wear and tear	Similar to a VFD	5 kVa–5 MW	Zero transfer time provides ideal solution to the lamp extinguishment. Careful attention must be made to maintenance and generator suitability
Delta Conversion On-Line	Similar to double conversion, except with an augmenting transformer connected to output	• No transfer time • Suitable for generators • Superior input characteristics	• Transformer adds weight	True on-line with integral power condition-ing	5 kVa–5 MW	Ideal power output with ideal power inputs, active front end, and suitable for all generators makes this the best solution.

Legend

Not Suitable	Severe Limitations	Good Solution	Best Solution

Harmonic Mitigation

Appendix A talks about power quality and the impact it can have on equipment life, including UV lamp life. Appendix A also talks about how power quality issues can extinguish lamps, and lead to an Off-Specification event of 5% or more.

As stated above, the *UV Disinfection Guidance Manual* indicates that any known phenomenon that can shut off the UV lamps must be accommodated in both design and operation[33]. The *UV Disinfection Guidance Manual* references IEEE 519 as a minimum requirement[34]. But is IEEE 519 truly the best design requirement?

IEEE 519 requires facilities to have the harmonics mitigated at the point where the utility connects to the facility's electrical distribution system. The point where these are connected is the point of common coupling (PCC). IEEE does not have any requirements for what the harmonic loading has to be at any point within the facility distribution system. Thus, if the PCC is satisfied, then it is perfectly acceptable according to IEEE 519 to have massive harmonic loading at the point in the electrical distribution system that is connected to the UV system.

From an ideal design standpoint, harmonics should be mitigated, not just for IEEE 519, but also within the power distribution system, and UV system. This is especially true when you consider that some of the equipment used in UV systems, and its power distribution may not be able to be replaced within the 1.5 day total flow allowance that the *UV Disinfection Guidance Manual* allows for unplanned outages[35,36].

To achieve this goal, harmonic mitigation must look at the entire facility. Thus, non-UV oriented loads, such as VFDs, as well as the loads from the UV system must be included. The UV equipment or the UPSs might have some inherent ability to negate the harmonics within the UV system. If this is the case, then this might make mitigation easier.

By doing facility-wide mitigation during design, you may discover the need to use active harmonic mitigation. This might negate the need to install 18-pulse or matrix filter drives on the motors and allow for lower cost 6-pulse drives instead.

Schneider Electric has a white paper discussing how to mitigate harmonics in UV systems. The paper is titled *Ultraviolet and Ozone Disinfection Electrical Application Guide*[37].

Another aspect of harmonic mitigation to consider is the need to oversize the neutral and the K rating of the transformers feeding the UV system. Failure to provide properly sized neutrals or K rating can lead to fires[38], or early failure of the transformers[39]. Both of these can put facility integrity, and thus UV system reliability at risk.

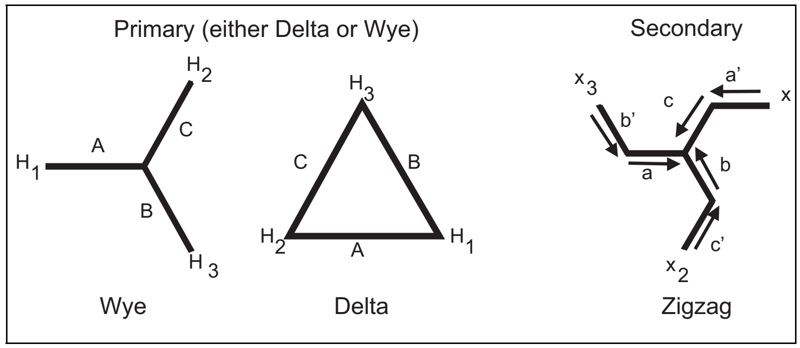
An active harmonic mitigation system, such as the Schneider Electric Accusine®, can offer two benefits over passive filters. First, the active harmonic system can help to protect against the need to revalidate. This is because the active harmonic system can change on the fly to dynamic harmonic loading. The second benefit is that the active harmonic system can adapt to the load if the UPS is in normal operation or if it is running on bypass. This is because integral, or external bypass systems also bypass any power filtering capability the UPS may have.

Finally, for small single-phase systems, the harmonic loading may be minor. In these systems, it may be possible to use harmonic mitigation transformers.

These transformers work by combining sine waves within the transformer. The windings of the transformer automatically shift the phases of the sine wave and then recombine them at the common nodes within the transformer. This is accomplished by winding the secondary on multiple phase cores within the transformer.

Look at Figure 11. In this case, the X3 secondary has part of the winding on core shared with the “B” side of the primary, and part of the windings on the “A” part of the primary.

Figure 11: Winding secondary on multiple cores to help mitigate harmonics[40]



The result of this type of winding is the desired phase shifting and recombination needed to help mitigate the harmonics.

Sag Ride-Through Conditioner

A Sag Ride-Through Conditioner (SRTC) is a very specific type of power conditioner where voltage sags are eliminated. Some of these sags can be very deep. SRTCs do not rely on batteries, and need a minimal power input to function.

Because of this need for minimal input power, a SRTC may not be able to provide power through an outage, during power transfer, or during breaker racking exercises. For these reasons, a SRTC cannot provide 100% uptime and is not an alternative to a UPS.

There are three instances in drinking water applications where a SRTC is desirable. These are:

- Where a UV reactor or reactors are dedicated to filter trains (Membrane or Gravity Filter)
- Systems that are not defined as PWS[41]
- Sag reduction to a UPS system

The first two examples have been discussed in the applications section. The third, using a SRTC to a UPS is discussed in the following paragraphs.

A UPS can supply power in case of complete power loss, or if a voltage sag is detected. This is done by one of two methods. Some UPS technologies have integrated sag protection that mimics a SRTC device. Others rely on the UPS’s backup batteries.

For these UPSs, voltage sag coverage could adversely impact battery life and long term maintenance cost. Using a SRTC on these types of UPSs can help protect the batteries.

Conclusion

The preceding text, and the following Appendices, examines the power side of the ultraviolet disinfection application.

This paper breaks down the *UV Disinfection Guidance Manual* and discusses its requirements as well as areas that are sometimes misunderstood. This includes the concept of the “Off-Spec Allowance” and how this has led some utilities and designers to a misunderstanding of the importance of power quality and power redundancy in the UV application. This paper then examines the *UV Disinfection Guidance Manual*, and other documents, and builds the case for why power quality and reliability are critical.

Next, the paper examined the range of UV applications and discussed each in depth. This was followed by suggested diagrams for each application class.

Finally the paper looked at the key concepts and technologies used in the UV application and discussed how they are applied and the benefits they present to the design.

With the understanding of the true intent of the *UV Disinfection Guidance Manual*, and the supportive research, it is clear the power system reliability can have a significant impact on the overall system integrity. Proper use of the concepts and techniques discussed can have a large impact on assuring system integrity.

Appendix A: Impact Of Power Quality On UV System Reliability

Power Quality Phenomena

Power supplied to most facilities is alternating current and the oscillation of voltage and current can be mapped as a sine wave. A perfectly smooth sine wave is desired by facility power distribution systems and treatment equipment. Unfortunately, there are factors that can distort or disrupt this perfectly clean sine wave. Distortions or disruptions can have an impact on all types of electric equipment. This ranges from a reduction of equipment lifetime to anomalous operation.

Power Quality is the term for cleanliness of a sine wave within a facility. Power Quality problems can usually be traced back to a variety of sources including storms, pumps, Variable Frequency Drives, and other equipment including Ozone and UV systems. Power quality issues can come from facility equipment, or equipment located off-site. In theory it is possible for a UV system to start behaving erratically after a building down the street modifies its electrical system[D].

Lamp Extinguishment During Power Quality Events

Power Quality (PQ) can lead to temporary light extinguishment, and to long term equipment damage.

Immediate lamp extinguishment can occur when the voltage drops by 10% for 0.5 cycles (8.3 milliseconds) or more[42]. Once extinguished, the amount of time required to re-strike is determined by the UV lamp type, duration of extinguishment, and surrounding water temperature[43]. Low Pressure Low Output (LP) lamps can reach full power in 15 seconds[44]. For other types of lamps, please see Table 2 below.

Table 2: UV Lamp Re-Strike Times[45]

Lamp Type	Cold Start[1]	Warm Start[2]
Low Pressure High Output (LPHO)	4–7 minutes	2–7 minutes
Medium Pressure (MP)	1–5 minutes	4–10 minutes

1 Cold Start occurs when UV lamps have not been operating for a significant period of time.

2 Warm Start occurs when UV lamps have just lost their arcs (e.g. voltage sag).

D Ideally, the building in this example should have considered the requirements on IEEE 519 and mitigated the harmonics accordingly. However, this does not always occur.

This chart highlights an interesting dilemma. In a running UV system, a half cycle voltage sag can cause the UV lamps to be Off-Specification for ten minutes. If two voltage sags occur about eleven minutes apart, this means only one minute of effective treatment in twenty-one minutes of time. Thus, relatively short duration repeating sags can have a large detrimental impact on operation.

For equipment damage, the dynamics are often thought to be voltage spikes[46]. But, the damage is actually caused by a current surge that accompanies a recovery from voltage sag[47]. Thus, eradicating the voltage sag can lead to elimination of the current surge.

While the preceding paragraphs help to define the problem, they are purely illustrative. To understand the real concern, we need a full understanding of power quality in water treatment facilities. Specific detailed extensive studies of power quality in water treatment facilities have not been found, and may not exist. However, some preliminary work exists and is helpful in understanding the power quality issues utilities are facing.

One of the more extensive studies is in the book *Integrating UV Disinfection into Existing Water Treatment Plants*. A chapter was dedicated to looking at power quality, and it takes two approaches at determining what kind of power quality issues treatment facilities may be facing.

The first approach relies on research done by the Electric Power Research Institute (EPRI). This research was done on United States based power utility electrical distribution systems and not on water and wastewater utilities[48]. Since most water and wastewater utilities are connected to a power utility's electrical distribution systems, the overall performance of these systems can serve as a good indicator.

In the second approach, several water facilities were monitored for power quality events[49]. These studies were of both short-term duration of just a few days[50], and long-term duration of between 5 to 13 months[51].

The water facilities studied represent a small fraction of the thousands of treatment facilities in the United States. But, these test sites were scattered across the country. Because of this geographic dispersion, these facilities provide an anecdotal viewpoint of power quality across the United States.

From these approaches, the authors of the book *Integrating UV Disinfection into Existing Water Treatment Plants* developed scenarios to help predict the maximum Off-Specification time that could occur in a treatment facility. These scenarios assumed that voltage sags would need to be at least 2 cycles to extinguish the arc. Then the scenarios assumed that each time it would take 10 minutes to re-strike. While these scenarios provide usable results, it has already been demonstrated that some types of UV lamps can come back into specification faster then 10 minutes, and that some systems can be sensitive to power quality events as short as a half-cycle. Thus, any given facility may be different than the numbers derived in the book *Integrating UV Disinfection into Existing Water Treatment Plants*.

For the EPRI method, it was determined that the average water treatment plant may experience 50 power quality events a year that could lead to an Off-Specification event[52]. From the assumptions detailed above, this would mean a total of 500 minutes of Off-Specification performance[53]. To illustrate a worst case scenario, it was assumed that all 50 events occur during a single month[54]. The result was a 1.2% Off-Specification total[55].

The actual plant studies in the book *Integrating UV Disinfection into Existing Water Treatment Plants* showed something a little different. The durations of the test for each of the eight facilities was different, but ranged from 7 to 15 months in duration[56]. Based on this test, they found that the Off-

Specification from power-related issues ranged from a best case of 0.01% to a worst case of 2.5%[57].

The data shows that power quality can impact a site's Off-Specification performance. The numbers are low, and at first it might be easy to dismiss it as insignificant to the "Off-Spec Allowance". But other factors, such as lamp failure, higher-than-rated flow rate, and film build-up on the quartz sleeve can contribute to Off-Specification total. When combined, power quality and other events can exceed the 5% Off-Specification limit.

What this book does not detail is the fact that local requirements may have a UV allowance that is much tighter than the EPA's "Off-Spec Allowance"[58]. For this reason, power quality by itself can lead to a violation of regulations.

Appendix B: Impact Of Maintenance On UV System's Reliability

The *UV Disinfection Guidance Manual* states that power to individual lamps should be supplied via GFI breakers, that these breakers must be trip tested every year, and maintained within the manufacturers' recommendations[59]. These GFI breakers are feed by upstream protection devices such as fuses and circuit breakers. Since these devices feed multiple lamps or reactors they must also be inspected and maintained regularly to assure reliable UV operation.

To better understand the impact proper maintenance has on these upstream protection devices, we need to understand the maintenance and reliability factors of fuses and circuit breakers.

Fuses

As mentioned in the *UV Disinfection Guidance Manual*, proper grounding and detected ground fault protection must be required[60]. An interesting fact is presented about fuses and detected ground faults:

> *"By themselves, fuses cannot provide ground-fault protection except for relatively high-level ground faults. When ground-fault protection is required in a fusible system, the disconnecting means (usually a switch, sometimes a contactor) must be capable of tripping automatically, and external relaying and a zero-sequence CT or set of residually-connected phase CTs must be installed to detect the ground faults and send the trip signal to the disconnecting means."*[61]

Thus, when applying a fuse in a UV application, the disconnecting means must be able to automatically open under a ground-fault. This means that the disconnecting means must have many of the same features found in a circuit breaker. Based on this alone, a circuit breaker is a better alternative to a fuse in a UV application.

But, what about fuses themselves? Do they have any maintenance requirements?

> *"While fuses themselves require no maintenance, this does not mean that a fusible system requires no preventative maintenance or testing. Fuse holders, cable connections, and disconnect switches (whether manually or automatically operated) must be periodically tested and maintained, just as in circuit breaker systems. Neglecting periodic operation of such devices, periodic maintenance requirements, and infrared scanning can lead to switch contacts that have welded shut, 'hot spots' at conductor connections, and other issues.*
>
> *If reliability and maintenance requirements of only the overcurrent protective devices are considered, it is true that fuses have a clear advantage over circuit breakers. In reality, however, both fusible and circuit breaker-based systems require at least some degree of periodic maintenance, giving neither type system a clear advantage in this area. For details on recommended maintenance procedures and intervals, contact the equipment manufacturer or see NFPA 70B,* Recommended Practice for Electrical Equipment Maintenance.*"*[62]

It is true that fuses do not need maintenance. But other aspects of a fuse-based system do require maintenance. On a system-wide basis, fuse protection is "on par" with circuit breakers from a maintenance standpoint. Furthermore, fuses introduce one additional hazard.

> *"Replacing fuses involves working 'on or near' exposed, energized equipment, which per NFPA 70E-2004 is only allowed if de-energizing creates 'additional or increased hazards or is infeasible due to equipment design or operational limits.' [6] Therefore, in most situations, replacing fuses in a panelboard or switchboard would require that the entire panel/switchboard be de-energized."*[63]

Replacement of a fuse requires a maintenance person to be exposed to live parts. To negate this, the entire panel or switchboard must be disconnected. If the entire UV system is on this single switchboard, then the entire treatment train must be shut down to comply with the *UV Disinfection Guidance Manual*[64].

Finally, fuses, or fuse links, must be replaced before service can be reenergized. Some power fuses can be hard to find in metropolitan areas, let alone rural areas. Thus, spares must be kept. If they are not kept locally, and need to be shipped in overnight, then the water system must either be shut down or the water must be considered to be Off-Specification until the fuse arrives. This can quickly consume the 1.5 day total flow "Off-Spec Allowance" granted by the EPA.

Fuses can introduce additional hazards, and are not really applicable to the detected ground fault requirements. Furthermore, replacement may jeopardize the 1.5 day "Off-Spec Allowance." Because of this, circuit breakers may represent a better solution. But circuit breakers also have maintenance requirements.

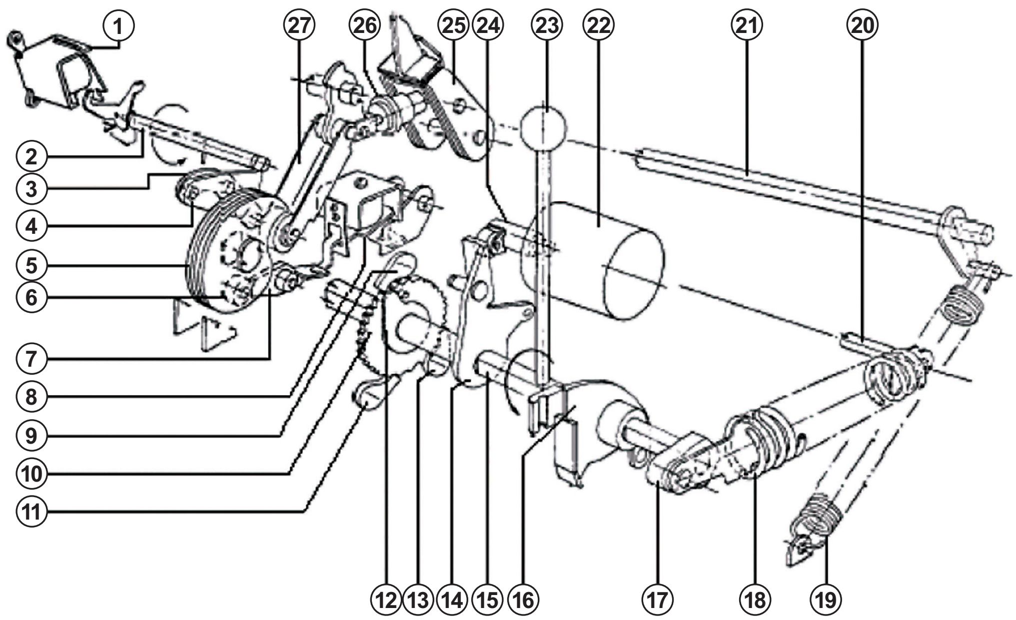
Circuit Breakers

Most of these feeder breakers will be low-voltage (under 600 Volts) or Medium Voltage devices categorized as either Molded Case Circuit Breakers or Power Circuit Breakers. The paper *Preventative Maintenance and Reliability of Low Voltage Overcurrent Protective Devices* indicates that if circuit breakers are not maintained according to manufacturers' recommendations for a period of 5 years, then there is a 50 percent chance the breaker will not behave as desired[65].

This paper also references two studies that were conducted by IEEE in 1974 and 1996[66]. The studies indicate that 32 percent of tested circuit breakers behaved abnormally[67]. What is also interesting is that 42 percent of all circuit breakers opened with no apparent reason[68]. This means that a UV system could go out with no warning, and with no diagnostic data captured in the SCADA or power monitoring system. OSHA requirements indicate that the cause of a trip must be found, and identified before the circuit breaker can be reengaged[69]. Thus, if a circuit breaker opens for an unknown reason, a complete short circuit test must be done on the wiring and any affected equipment. This leads to another interesting statistic: 73 percent of anomalous behavior led to "around-the-clock, all-out" efforts[70].

Finally, while power breakers have more maintenance requirements (see Figure 12 for typical Circuit Breaker Lubrication Points), 77 percent of fixed mounted breakers (including Molded Case) performed anomalously while in service[71] (see Table 3 for statistics). So why is there such a high anomaly rate for fixed breakers? Fixed breakers, including Molded Case, are often overlooked for maintenance purposes[72]. This occurs despite the fact that NFPA 70B, as well as most manufacturers, require that they be maintained regularly[73].

Figure 12: Power Circuit Breaker Lubrication Points[74]



1. Shunt Trip Device
2. Trip Shaft
3. Roller Constraining Link
4. Trip Latch
5. Close Cam
6. Stop Roller
7. Spring Release Latch
8. Spring Release Device
9. Oscillator Pawl
10. Ratchet Wheel
11. Hold Pawl
12. Drive Plate
13. Emergency Charge Pawl
14. Oscillator
15. Crank Shaft
16. Emergency Charge Device
17. Crank Arm
18. Closing Spring
19. Reset Spring
20. Closing Spring Anchor
21. Pole Shaft
22. Motor
23. Emergency Charge Handle
24. Motor Crank and Handle
25. Moving Contact Assembly
26. Insulating Link
27. Main Drive Link

Table 3: Circuit Breaker Anomalous Behavior Statistics[75]

32% of all circuit breakers experienced anomalous behavior while in service
9% of all circuit breakers experienced anomalous behavior while opening
7% of all circuit breakers experienced anomalous behavior due to damage while opening
42% of all circuit breakers experienced anomalous behavior by opening when it should not have
77% of fixed mounted (including 600 V molded case) circuit breakers experienced anomalous behavior
18% of all circuit breakers experienced anomalous behavior because of mechanical failure
23% of all circuit breakers experienced anomalous behavior because of an inadequate maintenance.
73% of all circuit breakers experienced anomalous behavior that required “around-the-clock, all-out” efforts.

Circuit breakers and fuses perform a critical job in protecting property and life from dangerous energy and fire. However, their long term reliability is dependent on proper maintenance. As stated above, a public water system must be designed and operated so that the lamps will be on during treatment[76]. The nature of circuit breakers and fuse reliability is well documented, and the maintenance aspects are well known. These must be considered in the design and operational aspect of a facility.

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