INTERCONNECTED PV –
THE UTILITY ACCESSIBLE EXTERNAL DISCONNECT SWITCH

Christopher Cook
E3 Energy Services, LLC
5019 N. 36th Street Ste 100
Arlington, VA 22207
ccook@e3energy.com

ABSTRACT

In virtually every jurisdiction where regulators address the adoption of interconnection rules for small scale photovoltaics and distributed generation, the need for an external utility accessible disconnect switch is debated. The important question for all those involved is whether this switch is a critical safety component or a useless equipment requirement?

All national technical standards for interconnected small generation systems contain requirements that the interconnection equipment disconnect automatically whenever the grid is down (i.e. de-energized). In addition the National Electric Code specifies several manual disconnect switches for interconnected systems to address the safety needs of maintenance workers and emergency personnel. Despite these substantial safeguards, some argue that to protect utility line workers, interconnected small generators must have an additional or redundant disconnect switch, external to the customer's building that is accessible to utility personnel. In most cases the requirement includes the option for the utility to lock the switch in the open or off position.

This paper will investigate whether this additional and redundant disconnect switch adds significantly to the safety of an small PV system using a code compliant inverter[i] for interconnection to the utility grid. The paper identifies circumstances where the proposed switch adds only a marginal increase in safety while complicating the procedures for the safe repair and maintenance of utility distribution circuits. It argues that the proponents of the external disconnect switch (EDS) for distributed generation may be creating more difficulties and inadvertent safety risks for utility line workers than they are solving.

Finally, the balance between cost and safety is discussed. The conclusion from this analysis is that when the marginal increase in safe interconnected generation operation is weighed against the cost to the generator, the balance tips sharply against a requirement for an auxiliary external disconnect switch. This conclusion becomes compelling when the costs for an EDS are compared to a hypothetically similar redundant safety requirement for a large central station generator.

1. WHAT IS THE PURPOSE OF AN "EXTERNAL DISCONNECT SWITCH"

Proponents of the external disconnect switch argue that this device is necessary to protect utility line workers from the possibility of shock or electrocution that could occur when a customer interconnects their own distributed generation then inadvertently re-energizes a utility distribution line under repair. The potential for back feed or re-energization exists because any interconnected distributed generation designed to export power has the physical capability, even if remote, to re-energize an entire distribution circuit when that circuit has been disconnected from the grid (either for repair or because a utility circuit breaker or fuse has opened and isolated the line).

For the purposes of this paper, only distributed generation systems that use an inverter for interconnection will be discussed[ii] with primary focus on PV systems. Inverters designed for interconnection should be compliant with the requirements for those devices contained in standards from the Institute of Electrical and Electronics Engineers (IEEE)[iii], the National Electric Code (NEC) and Underwriter's Laboratories (UL). Those standards and procedures require all customer owned inverters to automatically and instantly disconnect the generation source whenever the grid loses voltage (i.e. the grid goes down)[iv]. The inverter (generator) must also automatically disconnect for many grid out of bounds conditions including over-voltage, frequency and harmonics. In addition, compliant inverters must be able to detect and disconnect during what is known as a grid islanded condition. Islanding occurs when a down stream sub section of the utility grid is physically disconnected from the remainder of the grid but, through the operation of distributed generation on the disconnected portion, maintains voltage and energization.

In addition to the two different automatic disconnect switch conditions required by IEEE standards, the NEC imposes requirements for one or more manual disconnect switches[v]. For most customers the PV system disconnect switch must be located inside near the main circuit breaker panel (NEC Art. 705-12). The code requires these disconnects not only for servicing inverter equipment, but also in the case of emergency for firefighters and other emergency personnel[vi]. Often one manual disconnect switch would be used to disconnect the inverter from the grid while a second switch would be used to disconnect the PV source from the inverter (and in some cases there are several disconnects between the PV panels and the inverter – see Figure 1)[vii].

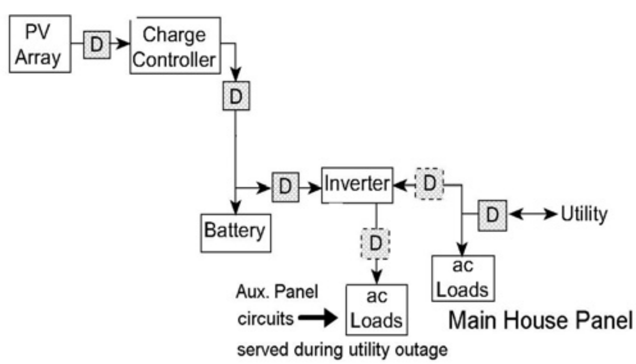

Figure 1 : Location of manual disconnects

The combined standards thus require any compliant inverter to have at least three disconnect switches (more likely four), any of which would prevent any back feed from the inverter/generator from the grid. Because there is no guarantee that these switches are always accessible to utility personnel -- even though it is assumed emergency personnel can access the NEC required switches -- many utilities request that an additional switch be added to the exterior of the customer's building or premises (usually near the meter). Utilities see the ability to access and lock open this switch as additional assurance that the customer distributed generation cannot reenergize a circuit or maintain an island.

2. HOW DOES THE EXTERNAL DISCONNECT SWITCH FIT IN WITH THE OTHER PROTECTIVE COMPONENTS?

There are three different approaches to distribution line worker safety typically employed in distribution line working safety rules. The first safety approach is to require all line workers to work on distribution circuits as if they were energized. Even if the line worker has disconnected a circuit, he or she is to wear protective gloving that would insulate them from any electrical current that was accidentally introduced into the wires on which they were working. If this is the distribution utility safety procedure, the customer generator external disconnect serves no critical safety function.

The second safety approach is for line workers to ground both upstream **and downstream** sides of the circuit on which they are working. The grounding[viii] prevents any current from flowing into the work area from either direction and assures the line worker cannot come into contact with harmful electrical currents. Since the downstream side is grounded, any customer sided generation would be short circuited and could not back feed lethal current. In this case, the external disconnect serves no safety purpose.

In the third case, the distribution safety procedure involves only grounding of the upstream side of the circuit. Since there is no grounding on the downstream side, any back feed current caused by an interconnected customer generator could pose a significant risk to line workers. Under this safety approach, **opening external disconnect switches would be a critical part of the safety procedure** and all such switches would have to be opened and locked before a line worker could commence repair[ix].

However, the third procedure presents a danger to the line worker. Only approved interconnected generators will have installed external disconnect switches. Any customer sited generation that has not been approved, but may have been accidentally interconnected through a fault of the homeowner, would pose a lethal threat to a line worker. Many home improvement stores sell thousands of portable generators, none of which have disconnect switches, either automatic or manual. While they are neither designed nor permitted to used in an interconnected mode, they can nonetheless be easily connected to the grid and accidentally re-energize an isolated utility circuit. Any portable generator connected by a customer to any household electrical outlet will back feed the entire utility distribution system (unless the customer has isolated their home or business by opening the main breaker at their site)[x]. Line workers are always at risk of the unapproved and accidentally interconnected generator. The third safety approach above provides no protection from the great risk of these generators and all safety minded utilities will avoid this line working procedure in favor of options one or two – those where the external disconnect serves no vital purpose.

Distribution utilities that adopt safety procedures one or two above, may still think that requiring external disconnects are worthwhile even if the EDS becomes a fourth or fifth level of redundant protection. A line worker could still be at risk of injury from an authorized inverter based generator interconnection if he or she failed to follow the adopted safety procedures. That failure notwithstanding, in order for a line worker to be injured, the following sequence of events would have to occur before the external disconnect was important:

1. The automatic inverter disconnect fails.
2. The output of the inverter (or aggregated generators on the circuit) would need to exactly match the load on the isolated portion of the circuit Otherwise the inverter would quickly (within milliseconds) lose all ability to provide harmful voltage or current.
3. If the isolated circuit load matched the inverter output, (an extremely rare event) an IEEE compliant inverters would detect the island condition and disconnect. That circuitry too would have to fail[xi].
4. The line worker would need to come in contact with the circuit.

So before the conditions would exist under which a line worker could be injured, a confluence of three or four highly improbable conditions would have to occur. Only if all of those events occurred would the **fifth** line of redundancy -- the external disconnect switch -- become crucial protection for a utility worker protection. And then only if the line worker had actually opened the EDS.

3. <u>USE OF THE EXTERNAL DISCONNECT SWITCH IN PRACTICE – POTENTIAL RISK TRADE-OFF</u>

While regulators may debate how many levels of redundancy are appropriate to create a safe environment for utility personnel and other customers, it is difficult to suggest ignoring any safety device that adds even a modicum of safety at a reasonable cost. If the cost is small (which as is described below it is not), then even a minor improvement in safety would still argue for the requirement of an EDS.

However, the need to use an external disconnect switch in practice may often present a risk of injury trade-off. In some cases, the need to access external switches may pose a greater threat of injury to line worker safety than not using the EDS. This is especially true when one considers the EDS is a fifth level redundant safety device.

Since many outages occur during inclement weather (ice or snow) the line worker may be called upon to traverse many snow or ice covered private drives, exit their vehicle, and walk through an unfamiliar ice or snow covered area to access the switch. Under normal weather conditions the line worker may still have to enter private property with unknown and uncontrollable hazards many of which pose safety hazard to the line worker. Line workers will be put in the unenviable position of either ignoring the EDS or entering into a known hazardous condition (deep snow or ice) to access and open the EDS.

Under the case where a utility has successfully argued for an external disconnect switch before regulators, it will pose significant liability problems for them if they then fail to incorporate the use of that switch as a fundamental part of their distribution safety procedures. Where utility management that has gone on record underscoring the need for the EDS in regulatory proceedings, it will be difficult to justify taking no further action to ensure that this switch is always used in practice. A utility that filed to incorporate the EDS into standard operating procedures, will likely face the prospect of punitive damages if a line worker is injured because this switch was ignored.

Assuming the utility does update its safe working procedures and requires every line worker to open every EDS on all distributed generation systems on a circuit before the worker can undertake repair, a worker that ignores this procedure would certainly be subject to disciplinary action[xii].

What then happens to a line worker in inclement weather when faced with the choice to violate a safety procedure instead of assuming the high risk of slip and fall injury by attempting to access and open the EDS? If they decide to repair a line without opening any EDS, they are at risk of disciplinary action. In addition that worker has significantly changed the liability equation for any injury related to any accidental re-energization. If it can be argued that the line worker has contributed to their own injury by ignoring a mandatory safety rule (operation of the EDS), liability for the injury related to the malfunction of an inverter's automatic disconnect is clouded.

In some states a contribution to one's own injury may be deemed to be contributory negligence. This legal theory, active in a handful of states, bars the injured line worker from recovering damages for their injury if they contributed, even remotely, to their own injury. It means they cannot recover from other parties that may have otherwise been liable.

In application, if an inverter malfunctioned and did not disconnect when the utility grid was de-energized, and that malfunction injured a line worker, ordinarily the injured worker could recover from the manufacturer of the defective product. However, in states where contributory negligence is the law, the manufacturer would argue that the line worker, by failing to use the EDS that was part of the utility's safe working rules, contributed to their own injury. If this is found to be true, the line worker is barred from any recovery for their injury[xiii].

It is important to note that in the above hypothetical the exclusion of the EDS as a required component would not have prevented the injury. But if there were no EDS required it would have allowed the line worker to fully recover for their injuries against the manufacturer of the defective equipment. While it is more valuable to prevent the injury in the first place, it is still of great societal value to ensure that an injured party may fully recover for his or her injuries.

This problem and the comparative safety trade off dilemma are removed if there is no requirement for an EDS. In that case, line workers can proceed to repair a line without the need to visit any customer distributed generation sites. Line workers can assume that the inverter automatic disconnect devices are working as designed, but will rely principally on grounding or working on the line as if energized as their primary protection from an accidental re-energization. If equipment malfunctions and the line worker is injured, the manufacturer is clearly liable. The line worker will not need to weigh the comparative risk of injury visiting each distributed generation site, against ignoring the EDS and working on the line with the switches closed.

4. <u>RELIABILITY – OUTAGE RESTORATION TIME IMPACTS</u>

Inclusion of an EDS will increase distribution outage times by significantly increasing the tasks a line worker must undertake to restore a line. If there are multiple customer generators on a distribution circuit that is damaged during a storm, the line worker must visit each customer location and open and lock out each and every EDS before beginning to repair the distribution circuit and restore service. If the customer generators are located in a geographically dispersed area, the time to visit each customer could be substantial.

After work on the circuit is complete, the line worker must then revisit each customer generator and remove the lockout and restore their distributed generation to operation. While other customers on the circuit will have had service restored by this time, it will delay a line worker from proceeding to repair other circuits before the lockouts are removed. If there are numerous outages from damaged circuits (as is the case in many storms), the additional time added to each circuit repair will have a cumulative negative impact on the time to restore service to all customers.

As long as distributed generation is an emerging market, visiting all customer-generator sites to open the EDS may not contribute to lengthy restoration delays. However, when there are hundreds of distributed generators on a circuit, the impact on restoration time could be significant. If the EDS is not required, restoration times are unaffected.

5. <u>RELATIVE COST OF AN EDS</u>

Regulators should not overlook cost impacts on the customer-generator of a required EDS. There is always a cost /safety trade off employed in regulatory decision making -- e.g. there are many additional safety devices that could be added to various aspects of the generation and delivery of electricity but are not required because of cost. It is understood that society will tolerate a certain degree of risk in the electricity business in order to keep costs reasonable. Regulators routinely balance costs against the safety benefits to arrive at the appropriate measure of each.

For example, most nuclear plants, which have the potential to harm significant numbers of people and cause immense and virtually permanent damage to property, require two or three levels of redundant safety devices to ensure critical systems operate as designed. Without a doubt, safety would be increased if every critical system had four or five levels of redundancy instead of two. Yet neither state nor federal regulators require this level of backup because the cost impact would be tremendous.

A similar process should guide the requirements on distributed generators. It is unfair to expect small generators to accommodate significantly higher levels of safety than that which has been determined to be the reasonable cost balance in the rest of the industry.

Many argue that the cost of an external disconnect switch for customer distributed generation is minor compared to the total installed cost of systems. The cost, while small in total dollars, nonetheless represents a significant percentage increase in the overall installed system cost. When compared to the economic output of the customer generator plant, the cost is unbearable.

Many of the commercially available small generator systems that use inverters cost from $4000 to $8000 per kilowatt installed. By comparison an EDS might cost from $120 to $400 installed. This represents only 1.5 to 10 percent of the installed cost of a one kilowatt system (typical for a residential customer) or a 0.2 to 1 percent increase for a typical small commercial system (10 kilowatts). However, the distributed generation industry is in its infancy and even the lowest installed costs today are expected to drop dramatically. In a number of years if lowest cost of a distributed generation system declines by 35 percent (to $2600 per kilowatt installed), the relative cost for the EDS would nearly double (there is no expected decrease in the installed cost of an EDS as it is a mature technology). For the smallest residential systems the EDS could **become a cost adder of over 15 percent of the overall cost of the distributed generation system**.

The inequity of the required EDS becomes apparent when these cost percentages are compared to other generation sources. When new nuclear plants were being built it is difficult to imagine regulators requiring utilities to include a fourth or fifth order of safety redundancy that would have increased the cost of plant construction by over $400 million dollars (10 percent of the total plant cost). Nuclear power advocates who balked at the increased costs related to secondary or tertiary redundant safety components would have strenuously opposed additional costs to added only a fourth or fifth level of redundant protection for critical systems. And this is for plants with much greater potential for injury than a small PV system.

The detrimental impact on distributed generation is magnified when the cost of an EDS is compared to the overall output of the small distributed generation system. For customers whose distributed generation use is limited to offsetting some or all of the customer's consumption (net metering), the power sold or swapped to the utility may represent less than $10 per month[xiv]. This may also be true for small commercial customers if the output of their distributed generation system has a close correlation to their load. If the economic output is worth only $10 per month, **the EDS would consume from 20 to 40 months of output from the plant**.

Comparing this to merchant plants provides a stark picture of the detrimental impact. A base load central station power plant that had the equivalent requirement imposed would **sacrifice 20 to 40 months of plant output** to satisfy the need for a fourth or fifth level of safety redundancy. For a typical 500 MW plant, the net economic effect would range from 180 to over 360 million dollars. Merchant plant owners would rightfully oppose such a requirement with vehemence. Such a requirement would undoubtedly have a negative impact on the construction of new merchant plants.

In comparison then, if regulators would find it overly harsh to require merchant plants to sacrifice nearly two years of plant output to satisfy a redundant safety requirement, or to add nearly one-half a billion dollars to nuclear plant construction costs, they should apply the same reasoning in rejecting the EDS for distributed generation.

6. REVIEW OF RECENT UTILITY COMMISSION DECISIONS ON THE EXTERNAL DISCONNECT SWITCH

Different state regulators pondering a requirement for the EDS have arrived at different conclusions. Some states deem inverter based interconnections as safe with no EDS while other states have concluded distributed generation is dangerous without it. In the realm of technical requirements and safety, this result is illogical.

What it means is that identical distributed generation systems on opposite sides of a state border are required to have different equipment to be deemed safe. The distributed generation industry is rightfully baffled as to why a system without an EDS can meet the definition of a safe installation in one location, while an identical system moved only a few miles away would be classified as a threat to the life and safety of a utility line worker. Nonetheless, this is the circumstance faced by the distributed generation industry.

In the most recent utility commission decision that addressed this matter, the Arkansas Public Service Commission decided that a "redundant visible, manual, lockable disconnect switch" did not need to be installed on customer's distributed generation facilities if that equipment met the IEEE requirements, was installed correctly and operated as designed. Despite a request for such a switch from every utility and Commission Staff, the Arkansas Commission reasoned that the safety requirements of IEEE were sufficient to ensure that distributed generation equipment would automatically disconnect when utility voltage "drops off".[xv]

Anecdotally, in addressing a request for high levels of insurance from distributed generation customers the Arkansas Commission noted that the threat to line workers was much greater from portable generators than a system installed in compliance with the IEEE and utility rules. Based on that fact, the Commission rejected the insurance requirement (though they did not apply this reasoning to the rejection of the need for an external disconnect).

Prior to the Arkansas Commission decision, the Virginia State Corporation Commission ruled that and EDS could be required on distributed generation systems using net metering. Despite a record that indicated that the switch might be unnecessary and elongate distribution outage restoration time, the Commission decided the EDS could be required as an option by the local distribution utility. The

Commission provided no criteria to the utilities on how the make that determination and seemingly left it to the arbitrary decision of the distribution company. It is unknown whether any of the Virginia utilities that adopted the EDS requirement have also modified their distribution safety procedures to incorporate the use of the switch or have identified the switch locations on distribution maps so line workers could use them if they needed to.

The Delaware Public Service Commission adopted a middle of the road approach when it approved the net metering tariff submitted by the sole investor owned utility in the State (Conectiv). Under that tariff, the utility recommended the customer install an external disconnect switch but allowed the customer to waive the switch requirement if the customer authorized the utility to remove the revenue meter to accomplish a disconnection. While the removal of the meter ensures that no customer distributed generation can re-energize a distribution circuit (when the meter is removed the customer and its generation is physically disconnected from the grid) it also removes electric service from the customer. The utility required that the customer understand and waive any complaints they might otherwise have had for the damages incurred from the disconnection of electric service.

None of the commission decisions addressed impacts on restoration time or the need for utilities to modify their distribution safety procedures or maps if they required an EDS. So while commissions may rule that an EDS is a critical part of line worker safety, there seems to be no follow up to whether the switches they required are ever used in practice. Purely anecdotal evidence from installers indicates once installed, the EDS are rarely if ever used.

The Arkansas Commission, the only to provide reasoning on their decision did note with concern that the threat posed to line workers from the renegade portable generator was the bigger threat by far and went on to suggest that utility safe working rules include a provision that all distribution repair be undertaken as if the line was live. Even though raised in dicta, that Commission has clearly encouraged utility management to adopt an approach that both protects line workers while eliminating the need for an EDS.

7. CONCLUSION

When the debate over the need for an redundant external disconnect switch on an IEEE and NEC compliant inverter based customer generator includes both a detailed review of how the switch would be used in practice, and the added safety value versus the cost, the arguments against requiring an EDS are compelling. First, the inclusion of the switch does little to enhance line worker protection since the far bigger threat to their safety is an unauthorized or accidental interconnection of a portable generator (which are much more prevalent than authorized interconnected distributed generators).

Second, the use of the switch in practice will cause a dilemma for the line worker. During inclement weather the worker will face either risk of injury from accessing all customer distributed generation switches which may be far off the road, and down long ice or snow covered private drives, or the line worker will ignore the switch and risk disciplinary action for failure to follow distribution safety procedures. If the line worker ignores the EDS and is injured by a malfunctioning inverter, the liability for that injury is clouded by the worker's breach of safety rules.

Third, if the switches are used religiously, it will increase outage restoration times as the line worker must visit each distributed generation installation before initiating work. This could have a seriously detrimental impact on the overall outage restoration time as the use of distributed generation grows.

Fourth, the cost of the EDS relative to the minimal added safety value is not justified under the traditional balancing of safety versus cost undertaken by utility regulators. The cost of adding an EDS to a small customer distributed generation facilitate would be the equivalent of requiring larger generation stations to spend well over 100 million dollars for a fourth or fifth level of redundant protection on a critical safety system. It is inequitable to require significantly higher investments in redundant safety equipment from small generation owners, when the same is not required on large central station plants (or anywhere in the utility business).

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[i] An inverter converts DC voltage and current to utility grade AC voltage and current. Many small generators as well as battery sources produce DC current.
[ii] Certain AC generators can be interconnected with the utility grid when their frequency is synchronized with that of grid. These generators may use mechanical or electronic devices to change the rotating speed of the generator and "lock in" when the generator and grid are synchronized. AC generators without this equipment cannot be interconnected and any attempt to do so will likely result in the destruction of the generator. However, when a utility circuit is de-energized, any generator can re-energize the circuit provided it has the capacity to meet all of the latent load on the circuit.
[iii] IEEE 929-2000
[iv] "Instantly" as reflected in the IEEE requirements, may allow two to three seconds before the disconnection is complete.
[v] NEC Art. 690-17 and Art. 230. See also John Wiles, *Home Power Magazine*, Vol. 42, pp. 78-80, 1994
[vi] Id.

[vii] Figure 1 is an edited version of Figure 5 in John Wiles, *Home Power Magazine,* Vol. 42, p. 79, 1994, used with permission.

[viii] According to John Wiles, of the Southwest Technology Development Institute at New Mexico State University and author of "Code Corner" in *Home Power* magazine, utility line workers use grounding conductors (often called chaining) of sufficient size to eliminate the possibility of shock from full load on a distribution circuit. A conductor of this size would easily ground any customer generator, compliant or otherwise and protect the workers from an accidental energization of the line. A customer's generator that remained connected to a grounded circuit would literally burn up.

[ix] Murray Davis of DTE Energy identified the three distribution safety procedures in conversations at the Federal Energy Regulatory Commission regarding the interconnection of small generation.

[x] The device to interconnect a generator is a simple extension cord with a male plug on each end. Anyone with the simplest knowledge of household wiring can make one of these cords.

[xi] This circuitry may not be a separate control circuit from the inverter automatic disconnection circuitry and a failure in one would mean both would fail. UL testing procedures include testing for inverter circuitry malfunction and require that even in the case of such a malfunction, the inverter must fail in the off condition, not energizing the distribution circuit. There has **never** been a reported case of an inverter failing in the "on" mode.

[xii] Conversation with S. Kraybill, Certified Safety Professional, Kraybill and Assoc., August 6, 2002. It would be difficult for a utility to insert numerous exceptions to the use of the EDS when it has argued the critical need for the device in a regulatory proceeding.

[xiii] In the majority of states, liability is not avoided as the states employ comparative negligence. Under that theory, damages will be reduced by a proportion that is related to the contribution to one's own injury. This could reduce damages considerably and would add significant complexity to the debate of who was as fault for the re-energization.

[xiv] This assumes that the customer is using a net metering arrangement where some of the customer's generation directly offsets the customer's electricity consumption while excess generation is swapped to the utility for kilowatt hour credits that are used by the customer in future days or months.
A one kilowatt system that produces about 2000 kWh per year (a solar PV system or wind generator) would produce kWh credits to a residential customer worth less than $7 per month at average US rates.

[xv] In the Matter of a Generic Proceeding to Establish Net metering Rules, Docket no. 02-046-R Order no. 3, June 3, 2002.