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Lecture #14

Installation Requirements

- Code
- Photovoltaic Array
- Wind Turbine
- Hydro Turbine
- Inverter and Controls
- Control Panel Array Wire Runs
- Battery Bank

Code Requirements

- The installation must comply with the provisions of the National Electrical Code (NEC) and any other applicable local, state or federal codes or practices.
- All required permits must be properly obtained and posted.
- All required inspections must be performed (i.e., Electrical/NEC, Local Building Codes Enforcement Office, etc.).

Code Requirements : some common installation problems

- Improper ampacity of conductors;
- Improper type of conductors;
- Improper or unsafe wiring methods;
- Lack or improper overcurrent protection on conductors;
- Inadequate number and placement of disconnects;
- Improper application of listed equipment;
- No, or underrated, short-circuit or overcurrent protection on battery circuits;
- Use of non-listed components when listed components are available;
- Improper system grounding;
- Lack or improper equipment grounding;
- Use of underrated hardware or components;
- Use of ac components (fuses and switches) in dc applications.

Standards

- Standards have been finalized for PV technology:
  - NEC article 690 addresses wiring and installation of PV systems
  - IEEE 929-2000 addresses utility interconnection of PV systems
  - UL 1741 addresses performance and testing requirements for static inverters and changes controllers used in PV systems.
- Other sources, such as small wind and hydro, do not have the same standards, but it is advisable for the designer to be aware of which practices can be applicable, particularly when PV is combined with wind or hydro.
- The IEEE Standard IEEE 1547 family covers distributed technologies as a whole : wind turbines, fuel cells, gas turbines and energy storage.

Grounding

- The purpose of grounding is to provide an alternate path for the current to flow when a current carrying conductor comes in contact, such as a fuse box, that people may touch.
- On the AC side of the system the white (neutral) wires and the green (ground) wires will ultimately lead to a copper ground rod outside. Eventually all the metal boxes, fixtures, frames and so on will be connected to this path.
- The DC side of the system is also connected to ground, because all the negative leads from wind, pv and hydro system will be connected at the batteries, and the battery will be also connected to the copper ground rod.

Bonding

- The point where AC neutral and ground wires joins with the DC negative leads is called point of bonding.
- It should be done at exactly one point of the system. It may be done at the ground rod, but it is usually done at the AC Service Panel.
- If a bypass switch is installed, to run the house from grid or generator power in case that an inverter fails, the bonding can also be done there.
- Local codes may vary on the point of bonding. Therefore, you have to explain the inspector simply that "you wish to bond the DC negative to the AC neutral and ground leads" and do whatever he or she suggests.

Lightning

- Solar arrays and wind towers are very vulnerable, because they offer an easy path between ground and sky for lightning.
- Water pumps are also vulnerable, because they connect water wells (ground) to outside structures.
- A lightning rod system provide a path for positive charges in the ground to cancel out the negative charges in the air. Therefore, they help to avoid the lightning as well as to provide a path, outside the circuits of your house, when the potential is too high and the light will eventually strike.
- Surge arrestors are like "clamps" in most cases. They go across the live wires with another wire going to ground.
- Surge capacitors are also recommended, because they will catch those high voltage spikes on the AC line that are too fast for a surge arrestor.

Lightning – Cont.

- Most inverter damage is caused by surges on the AC side coming in through house or generator wiring. In many systems with a backup generator, the generator is located outside quite some distance from the inverter, and is a common hit point for lightning strikes.
- For most systems to get the best protection, you should have a DC surge arrestor, on the input side from the array - this should go on the INPUT to the charge controller. It should be as near the charge controller as possible.
- On the AC side (and this applies to BOTH the inverter AC input and AC output (for generator and/or grid tie systems) you should have both an AC surge arrestor and a surge capacitor.

Switchgear

- All renewable energy systems will have some form of switchgear.
- The purpose of the switchgear is to isolate the generating unit when necessary, have control over the electrical power flow and protect the system.
- Some common switchgears are isolators, switches, fuses and circuit breakers.
- Switchgears are designed to protect against overloading and short-circuiting.
- They are crucial for the safety of persons and property and should never be neglected, even for low-voltage systems.
- The generating system and the load must also be protected against over- or under-voltage and frequency.

Suggested website http://store.solar-electric.com

Wiring

- NEC requires 12 AWG or larger conductors to be used with systems under 50 volts.
- Temperatures in the vicinity of photovoltaic arrays can be higher than 60 ºC. Therefore, wires are required proper temperature rating and sunlight resistance.
- When wires are used for moving parts, for example, photovoltaic arrays with tilt adjustment, or mechanical tracker, flexible cords can be used, but must be temperature derated in the range of 0.3 to 0.6
- DC wire colors = RED for positive and WHITE for negative
- AC wire colors = BLACK for hot, WHITE for neutral and GREEN for ground.

Wiring – Cont.

- NEC tables 310.6 and 310.7 give the ampacity of various sized conductors at temperature of 30 ºC. Several adjustments must be made in accordance to section 310.15
- The ampacity of conductors should be at least 125% of the rated short-circuit current. For a PV it is straightforward, for wind and hydro turbines, they will depend on the electrical machine.
- The ampacity of conductor to and from inverters must be at least 125% of the rated operating current at maximum power.

Circuit Breakers and Fuses

- Circuit breakers and fuses must be dc rated, listed, and able to handle the short-circuit currents they may be subjected.
- The use of ac-only rated circuit breakers and fuses are not recommended for the dc circuits.
- Current-limiting fuses such as the Class RK-5 or Class T fuses are used to protect wiring and devices connected to batteries since large fault currents are possible.
- Where current-limiting fuses are not used, each overcurrent device in the circuit (either a fuse or circuit breaker) must have an interrupt rating capable of withstanding any fault currents that may occur. Typically, overcurrent devices with interrupt ratings of 20,000 amps or higher are used with battery circuits.
- In the dc circuits of a PV system, only overcurrent devices listed for dc operation are allowed by the *NEC*.

Ground-fault Protection

- Section 690-5 (Ground-fault Protection) of the 1999 *NEC* requires that any PV array installed on a dwelling be provided with ground-fault protection.
- Utility-interactive inverters may contain ground-fault protection circuits or the ground-fault protection is available as an option.
- Stand-alone and utility-interactive PV systems that are roof-mounted on dwellings need ground-fault protection.

Disconnecting the Photovoltaic Array

- A disconnecting means must isolate the inverter from the PV power source. For outdoors use it must be raintight (NEMA 3R).
- Utility intertie inverters that utilize PV arrays with voltages above 250VDC require a disconnect rated for 600VDC to perform this function.
- For example, Square-D has a 30 amp 3-pole safety switch is UL listed to handle 13A at 600VDC per pole. It can be used for disconnecting up to three PV arrays for three inverters. Other inverter companies such as Xantrex also provide dc disconnect switches.
- The PV disconnect is ALSO the same DC rated breaker that disconnects the BATTERY bank from the INVERTER.
- The DC Disconnect Point is the point of common coupling of all incoming and outgoing dc circuits

Disconnecting the Wind Turbine

- It is not recommended to electrically disconnect the wind turbine !
- The wind turbine may generate voltages during connection that may damage the circuits.
- A switch that short-circuit the windings of a wind turbine should be used as “disconnecting means” although electrical inspectors may find hard to accept that a short-circuit switch is better than a series connected switch. It may be the case that you need TWO switches, one in series, another in parallel.
- A mechanical brake, provided by the wind turbine manufacturer should be used as well, in addition to short-circuit the machine windings.

Disconnecting the Hydro Turbine

- Instead of an electrical brake (as for a wind generator) or a circuit breaker (like with a solar array), the hydro turbine is stopped with ball valves located near the nozzles.
- The ball valves will stop the turbine from spinning whenever you need to shut off the power.
- You will have to check with the hydro turbine manufacturer about the requirement of parallel/series electrical switches.
- Of course the electrical inspector will "feel strange" in looking at plumbing stuff, but you have to explain him/her how this option actually shuts down the hydro power source…

Photovoltaic Array

- Modules must be UL Listed and must be properly installed according to manufacturer's instructions.
- Overcurrent protection must be provided in accordance with the provisions of the NEC.
- Any exposed wiring (not contained in conduit or other enclosures) used to connect panels or other equipment must be properly insulated.
- All insulation on wiring must be UV-rated and temperature-rated at 90° C or higher.

Photovoltaic Array – Cont.

- All frames, supports, boxes and other non-insulated/exposed metal parts, etc., must be grounded and bonded in accordance with the provisions of the NEC.
- The array must be fully grounded, every module to every panel frame, to the entire array.
- The array to a copper ground, to a heavy buried ground, connected to the common house ground.

Wind Turbine Tower

- An 80- to 120-foot tower is usually supplied along with the wind turbine.
- Relatively small investments in increased tower height can yield very high rates of return in power production. For instance, installing a 10-kW generator on a 100-foot tower rather than a 60-foot tower involves a 10% increase in overall system cost but can result in 29% more power.
- Taller towers also raise blades above air turbulence, allowing the turbines to produce more power and be proportionally more silent.
- A rule of thumb for proper and efficient operation of a wind turbine is that the bottom of the turbine's blades should be at least 10 feet (3 meters) above the top of anything within 300 feet (about 100 meters).
- Several types of towers are available. Each type has its advantages; the most economical type of tower is the guyed lattice tower, but a hinged tower can be easier for you to install yourself and provides easier access for maintenance.

Wind Turbine

- All wiring must conform to the NEC. Overcurrent protection must be provided in accordance with the provisions of the NEC.
- The use of electrical conduit for wiring between components is highly recommended. Any exposed wiring, not contained in conduit or other enclosures, that is used to connect turbines, inverters or other equipment, must be properly insulated.
- The insulation on any exposed outdoor wiring must be UV-rated.
- The wind turbine tower must be well-grounded and bonded in accordance with the provisions of the NEC and any other applicable codes.

Wind Turbine – Cont.

- Appropriate lightning protection and surge suppression must be installed in accordance with the provisions of the NEC and any other applicable codes.
- All frames, supports, boxes and other non-insulated/exposed metal parts, etc., must be grounded and bonded in accordance with the provisions of the NEC.
- The insulation on any wiring subject to elevated ambient temperatures must be rated at 90° C or higher in accordance with the provisions of the NEC.
- The wind turbine must be periodically checked for any objects that may obstruct the blades or any moving parts, particularly before starting system start-up.
- Mechanical brakes for large turbines, or a switch that shorts all winding of small turbines can be used for breaking the motion.

Wind Turbine – Cont.

- Since the wind tower is probably the tallest structure around your property, proper grounding is really required.
- A heavy copper wire (#6 or bigger), should connect the tower structure in many places. Each of the guy wire that support the structure should be connected to a copper rod, that accepts the wires from the tower.
- Bury the structure at least 6 inches below the surface and drive the connection to the common grounding point in the house.
- If the wind turbine is very far from the house and a distribution line is used, the grounding on the turbine side is probably different from the house side.
- In this case, it is recommended to use transformers for stepping up and down the voltage.
- Therefore, same procedures used for transformer grounding in distribution lines should be implemented

Hydro Turbine

- Switchgear is similar to a wind turbine installation
- Protection against over- or under-voltage and frequency : linked to automatically activate a shutdown of the water flow into the turbine and power generation in the event of a critical malfunction.
- Lightning protection must also be installed where power from a micro-hydropower system is transmitted from the powerhouse to a load by means of a transmission line. The transmission line must be protected against direct and indirect lightning strikes.
- All electrical equipment should be grounded to protect against electric shock due to electric leakage or faulty wiring of the equipment.

Hydro Turbine – Cont.

- Wiring and grounding should meet national standards and be tested thoroughly.
- Ground fault interrupters will disconnect the power if faults such as metal parts in the equipment become live or if there is a leakage of power to ground due to faulty insulation.
- Adequate guards for the turbine and all moving mechanical equipment must be provided and should be periodically checked, particularly before starting the turbine.

Hydro Turbine – Cont.

- A hydro turbine is in contact with water, making a very good path of positive charges in the ground to the air.
- Therefore, a heavy copper wire (#6 or bigger), should connect qll the turbine structures, and should be connected to a buried copper rod to the common grounding point in the house.
- If the hydro turbine is very far from the house and a distribution line is used, the grounding on the turbine side is probably different from the house side.
- It is recommended to use transformers for stepping up and down the voltage.
- Therefore, same procedures used for transformer grounding in distribution lines should be implemented.

Stand Alone Systems

Inverter and Controls

- The inverter and controls must be mounted in a clean, dry environment away from high-moisture and high-heat sources, or otherwise rated for outdoor installation.
- The inverter must be certified as compliant with the requirements of IEEE 929 for small photovoltaic systems and with UL 1741.
- The system should be equipped with visual indicators and/or controls:
  - On/off switch
  - Operating mode setting indicator
  - AC/DC overcurrent protection
  - Operating status indicator
  - Battery state of charge (E-meter)

Inverter and Controls – Cont.

- Warning labels must be posted on the control panels and junction boxes indicating that the circuits are energized by an alternate power source independent of utility-provided power.
- All interconnecting wires must be copper.
- All wiring splices must be contained in UL-approved workboxes.
- Operating instructions must be posted on or near the system.

Control Panel Array Wire Runs

- Areas where wiring passes through ceilings, walls or other areas of the building must be properly restored and sealed.
- All interconnecting wires must be copper.
- Wiring connections must have strain relief at all connections to junction boxes and control panels.
- Warning labels must be affixed to the control panels and junction boxes indicating that the circuits may be "live" when the building power and/or breakers are shut off or tripped.
- Insulation in areas where wiring is installed must be provided and access doors to these areas must be properly sealed and gasketed.

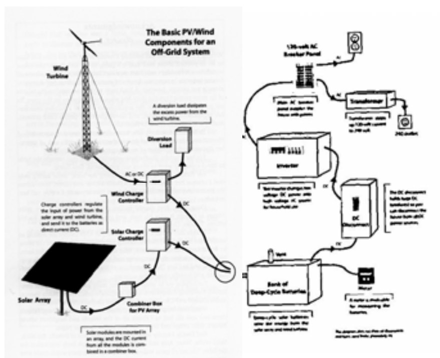
Control Panel Array Wire Runs – Cont.

- Wiring passing through the roof and/or walls of the structure must be properly booted and sealed.
- Wiring connections must be properly made, insulated and weather-protected.
- All wiring must be attached to the system components by the use of strain reliefs or cable clamps.
- All outside wiring must be rated for wet conditions and/or encased in liquid-tight conduit.
- Insulation on any wiring located in areas with potential high ambient temperature must be rated at 90° C or higher.

Batteries

- The batteries must be installed according to the manufacturer's instructions.
- Battery terminals must be adequately protected from accidental contact.
- DC-rated overcurrent protection must be provided in accordance with the provisions of the NEC
- The batteries must ALWAYS be kept in a well ventilated area. They produce Hydrogen, that can explode if allowed to build up.
- Batteries contain sulphuric acid that burns skin on contact.

Stand Alone Household Wind/PV System



Utility Interactive Systems

Utility Interactive Inverters

- Utility interactive inverters inject power to the grid making possible net-metering applications.
- Those inverters must adhere to many standards and certifications as regarding interconnection, power quality, safety and islanding detection.
- The inverters have internal control schemes to detect islanding :
  - **Variation of active power**
  - **Variation of reactive power**

PV versus Rotating Generators

- **Mode of operation of a photovoltaic PCU and a rotating-type generator that may be interconnected with the utility grid ?**
- **A rotating generator connected directly to the grid acts as a *voltage source* that can generate independent of the grid, and is synchronized with it.**
- **The photovoltaic PCU, in general, acts as a sinusoidal *current source* that is only capable of feeding the utility line when voltage and frequency are within standard limits.**
- **Rotating generators with inverter interconnection will mostly behave as a *current source* as well.**
- **Therefore it is the power electronics with associated control circuit that imposes a current source behavior.**

Intro to Islanding and Fault Considerations

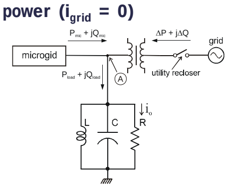
- The possibility of islanding, or independent operation of a section of the distribution system powered by A PV or an inverter based system is far less likely than with a rotating generator, as line voltage is not generally maintained by PCUs and there are embedded protective monitoring schemes.
- Under fault conditions, a rotating generator can deliver most of its spinning energy into the fault. A photovoltaic PCU, being in general a controlled-current device, will naturally limit the current into a fault to little more than normal operating current. As the photovoltaic cells themselves act as current-limited devices (as output current is proportional to sunlight), these too act to limit longer term fault currents.

Islanding

- Islanding is defined when the Distributed Energy Resource (it does not matter if renewable or alternative) does not cease to operate when the grid is disconnected.
- A desired islanding is a DER running without connection to the grid intentionally.
- An undesired islanding is a DER connected to the grid, when the utility disconnected the power and it can pose danger to grid maintenance personnel and unsafe reclosures (because grid and local inverter will be in different voltage levels and out of phase).

Islanding Testing

- The inverter should cease to energize the utility in 10 cycles (200 ms for 50 Hz) having an RLC local load with Q = 2.5P.
- The IEEE 929 was incorporated in IEEE 1547.
- The test should be repeated for 25, 50, 75 and 100% P with a perfect balanced power ($i_{grid} = 0$)



- We need : over voltage relay (OVR), under voltage relay (UVR), over frequency relay (UVR), and under frequency relay (UFR) for detection of unintentional islanding.

Utility Interactive Inverters
- Inverter Resident Islanding Detection Methods -

- The inverter deliberately introduces periodic variations in its power output and monitors the response of the parameters voltage, current and frequency. If the grid is stable the parameters will hardly change at all while in an islanding situation the effects of power variation can be clearly detected.
- This method works very well for a single inverter; as the number of independent power producers in the grid increases, the reliability of islanding detection decreases.
- Therefore, other methods such as online impedance measurement has been under research.
- Communication among interconnected inverters can improve the detection. There is a working IEEE group on this issue.

References

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- Smith, G.A. Onions, P.A. Infield, D.G, "Predicting Islanding Operation of Grid Connected PV Inverters" IEE Proceedings of Electric Power Applications, Vol. 147. No. 1, January, 2000