



Interpretation

Section 9. Grounding methods for electric supply and communications facilities

Rule 096C Ground resistance requirements – Multi-grounded systems (2007 Edition, page 27) (6 October 2009) IR559

Question: The opinion of engineers in the industry is divided on whether the “four-grounds each mile” stated under Rule 96C is applicable to medium voltage underground cable systems for utility scale wind farms. These wind farm medium voltage cable systems typically consist of three underground single phase cables with Jacketed Concentric Neutrals (JCN). Each wind turbine would connect to the medium voltage system via LV/34.5 kV step-up transformer. The 34.5 kV underground cable system would be terminated at a 34.5 kV/HV substation before the wind farm is interconnected to the grid. A typical one-line diagram of a wind farm is shown below.

The 34.5 underground cable system could have a Delta connection at the turbine step-up transformers (LV/34.5 kV – Wye/Delta) and a Wye connection at the main power transformer at the substation. The cable concentric neutrals would be effectively grounded and bonded to the main power transformer neutral at the substation. The concentric neutrals will also be bonded to the low voltage secondary neutral of the turbine step-up transformers.

For the underground cable system described above, is the “four-grounds each mile” requirement stated in Rule 96C applicable? Additional information on different opinions in the industry is provided below. The additional details furnished are for information only and intended to further clarify the main question for which a code interpretation is sought.

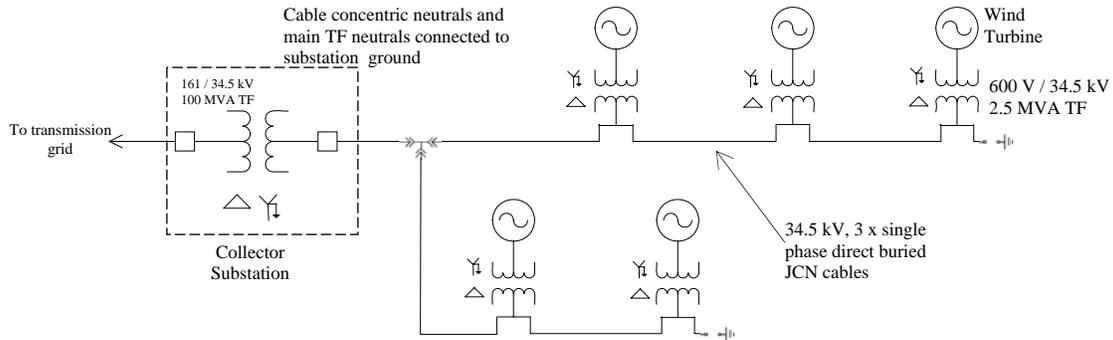


Figure 1: Typical Wind farm network- single line diagram (only a few turbines are shown)

Discussion: The 35 kV direct-buried cable concentric neutrals (JCN) of a wind farm collector system are typically grounded to meet four ground points each mile to meet the NESC Rule 96C requirement. Questions have been raised regarding the applicability of Rule 96C when the wind-turbine step-up transformers (LV/34.5 kV) have an ungrounded Delta connection on the high side (34.5 kV side). The main rationale presented for not applying the “4 grounds per mile” is as follows.

- a) The wind farm collector cables that are connected Delta at the turbine pad mount transformers do not have a “multi-grounded system neutral” that is subject to Rule 96C. Therefore, “four-grounds each mile” rule is not applicable.

The arguments supporting the applicability of Rule 96C for wind farm installations include the following.

- i) When three single phase cables with concentric neutrals are buried in the same trench, each concentric neutral becomes a neutral sub-conductor. The concentric neutrals are grounded either at the substation or pad-mount transformer locations or both. NEC (310.6 NEC-2008) requires that medium voltage cable shields be Effectively grounded [2]. The reasons for cable shield grounding are to confine electric field within the cable, to obtain uniform radial distribution of electric field, to protect against induced voltages, and to reduce shock hazards [4]. With the shield grounded at one point, induced voltage on the shield can be significant and create a shock hazard. A multi ground concentric neutral will help ensure that the concentric neutrals are effectively grounded and that the shield grounding requirements are met. **The practice of multi grounding cable shields includes the**

grounding of concentric cable neutrals on power cables thereby extending the need for multi-grounding of neutrals on the power systems [4].

ii) Also, during ground fault conditions, the concentric neutral will carry large fault currents even when the cables are Delta connected at the turbine transformer locations. This is due to the fact that the concentric neutrals are bonded and grounded at the substation where the main substation transformer typically has a “neutral ground” on the 34.5 kV side. Complying with Rule 96 would reduce unsafe voltage build-ups during ground fault conditions.

A previous rule interpretation on Rule 96C (IR532) [3] had also discussed the issues related to underground cable shield grounding. IR532 interpretation discussion seems to be on a typical “multi-grounded” underground distribution system. The interpretation sought with this request is specifically for a wind-farm collector system where the medium voltage 34.5 kV/LV transformers are connected in “Delta”.

REFERENCES

1. NESC C2-2007, 2007. National Electrical Safety Code
2. NEC/NFPA 70 -2008, 2008. National Electrical Code
3. NESC – IR532, Rule 96C Interpretation, May 2003
4. Nelson, John, IEEE PCIC-2002-xx, 2002. The Grounding of Power Systems above 600 V: A Practical View Point.

Interpretation

Summary

The NESC applies to utility-scale wind farms, including the wind turbine generators, collector system cables and associated transformers shown in this Interpretation Request (“IR”). Whether four grounds are specifically required in each mile of the collector system cable neutrals depend upon the type of grounding selected and used at the individual step-up transformers: separate or interconnected grounding conductors and electrodes.

If the grounding conductors/electrodes for the step-up transformer cases, surge arrestors and associated equipment are separated from the step-up transformer secondary neutral grounding conductor/electrode, NESC rules do not require the collector cable neutrals to be grounded four times in each mile (but see specific requirements for random lay cable). However, the NESC rules do require the cable neutrals to be effectively grounded.

If the grounding conductors for the above items are interconnected using a single grounding conductor/electrode, the collector cable neutrals must be grounded at least four times in each mile of the entire collector system. NESC rules allow such interconnection providing applicable rules are met; the rules do not require interconnection.

Specific NESC requirements and details are covered in the following discussion.

Introduction

This IR includes a description and a simplified single-line diagram for a typical utility-scale wind farm. As described and shown, the collector system consists of medium-voltage (34.5 kV) direct-buried cables with concentric neutrals bonded to the collector substation transformer grounded neutral point (34.5 kV side) and also bonded to the low-voltage secondary neutral at each wind turbine step-up transformer. The IR did not state whether or not various classes and types of equipment (such as surge arresters, step-up transformer cases and grounded neutral conductors) would be interconnected by means of a single grounding conductor. As well, it did not state if the concentric neutral jacket is insulating or semi-conductive. The basic question asked is whether: (1) is the grounding of the collector system cables adequate as described, or (2) must the cables also be grounded four times in each mile of cable run assuming that the described grounding points do not provide such grounding.

Because large-scale wind farms are a relatively new and emerging form of cogeneration, or in this situation renewable energy, specific NESC rules have not been developed for wind farms. Consequently, both careful consideration of all factors and good engineering judgment are required in the design and operation of wind farm systems to ensure that all applicable NESC rules are met. See also Rule 012C regarding items not specified in the NESC rules.

Several factors must be considered to determine application of existing NESC rules to grounding of the described system. Note that this interpretation is limited to the system described in the IR.

Supply Station

As described, each wind turbine and its associated step-up transformer is a supply station. See definition for *electric supply station*. Accordingly, each wind turbine/step-up transformer must meet all applicable NESC *Part 1 – Electric Supply Stations* rules. See also Rule 096B for specific supply station grounding requirements.

Hybrid System

As described, the collector system (the 34.5 kV cables) is a hybrid system. It is a grounded system in normal operation. However, the collector system is an ungrounded delta system when the wind turbines are generating and the collector station breaker is open. Collector system cable grounding must satisfy both types of operation – normal and breaker open – unless the system is designed and operated to ensure that the collector system cannot be energized by one or more of the wind turbine step-up transformers when the collector substation breaker is open.

Separation of Grounding Conductors

One of the basic system grounding considerations is whether grounding conductors and electrodes for various classes of equipment and circuits must be separated or if they may be combined. See Rule 097A. If they are separated, note that the grounding conductors/electrodes for the surge arresters and wind turbine step-up transformer cases must be separated from the step-up low-voltage secondary neutral grounding conductor/electrode. In effect, this would prohibit bonding the collector system concentric neutrals to the low-voltage grounded secondary neutral at the step-up transformers. However, the grounding conductors may be run separately to a sufficiently heavy ground bus or system ground cable that is well connected to ground at more than one point.

Separate Grounding Conductors/Electrodes

As stated above, the grounding conductors/electrodes for surge arresters and wind turbine step-up transformer cases must be separated from the low-voltage step-up transformer secondary neutral grounding conductor/electrode if the system is designed for separation of grounding conductors/electrodes. All applicable Rule 096 and 097 requirements must be met. In particular, see Rules 096A, 096D, 097A, 097D1 and 097F.

Interconnected Grounding Conductors/Electrodes

The surge arrester, step-up transformer case and secondary neutral grounding conductors **may** be interconnected utilizing a single grounding conductor if all applicable Rule 096 and 097 requirements are met. In particular, see Rules 096A, 096C, 097B, 097C and 097D2. Note that this type of grounding requires the collector system concentric neutral cables to be grounded not less than four times in each mile of the entire collector cable system. Also, the grounded neutral must be continuous from the collector substation to each end of the described collector cable system; in general, the grounded neutral must cover the entire multi-grounded collector system whether the construction is overhead, underground or a combination of both. See also IR 532 for discussion of four grounds in each running mile segment.

Cable Grounding

As described, the collector system consists of three direct-buried, single-phase cables, each with jacketed concentric neutral cables. The IR does not state whether the jacket is insulating or semi-conductive. In either case, several rules apply to grounding these cables:

- Rule 314 requires cable sheaths and shields to be **effectively grounded**.
- Rule 350B requires direct-buried cables operating above 600 V to ground to have a continuous metallic shield, sheath or concentric neutral that is **effectively grounded**.
- Rule 354, which covers random separation of direct-buried cables from underground structures or other cables, may or may not apply to wind farms as depicted in this IR. Nevertheless, Rules 354D2 and 354D3 contain specific requirements for grounding cables if Rule 354 does apply and contain guidance as to what is generally considered effectively grounded in other circumstances. In addition, Rule 094B5 contains similar requirements for semi-conductive jacketed cables. Note that Rule 354D3c requires eight grounds in each mile for insulating jacketed cable in random lay.

Consequently the concentric neutrals of subject collector system cables must be effectively grounded. See definition for *effectively grounded*. While these cable grounding rules do not specifically require four grounds in each mile of cable, such grounding usually satisfies an effective grounding requirement. As stated above, insulating jacketed cable in random lay does require eight grounds in each mile of cable.

Additional Comments

The following comments are for your information and not part of the official interpretation:

- The NESC is considering a Change Proposal for the 2012 Edition that would require effectively grounded neutral conductors to have not less than four grounds in each mile of such conductor. See change proposal 3450 in the 2012 NESC Preprint.
- The IEEE PES Wind Power Coordinating Committee has established a Wind Plant Collector System Design WG. This WG is actively investigating issues associated with grounding of cable sheaths as discussed in this request for interpretation. The cognizant NESC technical subcommittees look forward to recommendations from the WG.