Electrical Power

Part I: Generation
Part II: Distribution Systems
Part III: Transformers
Part IV: Transmission Lines
Part V: The National Electrical Safety Code (NESC)

Overview / Structure of NESC / Rule Highlights

by

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Nomenclature[1]

A	ABCD parameter	-
a	phase	-
A	area	m^2
B	ABCD parameter	-
B	magnetic flux density	T
B	magnetic flux density	T
B	susceptance	S, Ω^{-1}, or mho
b	phase	-
c	speed of light	m/s
C	capacitance	F
C	ABCD parameter	-
c	phase	-
D	ABCD parameter	-
D	distance	m
E	electric field strength	V/m
E	energy	J
E	voltage (generated)	V
f	frequency	Hz, s^{-1}, cycles/s
f_{droop}	frequency droop	Hz/kW
G	conductance	S, Ω^{-1}, or mho
GMD	geometric mean distance	m
GMR	geometric mean radius	m
h	specific enthalpy	kJ/kg
I	effective or DC current	A
I	rms phasor current	A
K	correction factor	-
K	skin effect ratio	-
l	length	m
L	inductance	H
m	mass	kg

[1] Not all the nomenclature, symbols, or subscripts may be used in this course—but they are related, and may be found when reviewing the references listed for further information. Further, all the nomenclature, symbols, or subscripts will be found in all "Parts" of this complete course. For guidance on nomenclature, symbols, and electrical graphics: IEEE 280-2021. IEEE Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering. New York: IEEE; and IEEE 315-1975. Graphic Symbols for Electrical and Electronics Diagrams. New York: IEEE, approved 1975, reaffirmed 1993.

M	mutual inductance	H
n	Steinmetz exponent	-
N	number of turns	-
n_s	synchronous speed	r/min or min^{-1}
p	pressure	Pa
P	number of poles	-
P	power	W
pf	power factor	-
pu	per unit	-
Q	heat	J
r	radius	m
R	resistance	Ω
s	specific entropy	kJ/kg×K
S	apparent power	kVA
SWR	standing wave ratio	-
T	temperature	ºC or K
v	wind velocity	km/hr
V	effective or DC voltage	V
v	velocity (speed)	m/s
V	rms phasor voltage	V
V_{droop}	voltage droop	V/kVAR
VR	voltage regulation	-
W	work	kJ
X	reactance	Ω
x	variable	-
Y	admittance	S, Ω^{-1}, or mho
y	admittance per unit length	S/m, 1/Ω×m Ω^{-1}, or mho/m [℧ / m]
Z	impedance	Ω
z	impedance per unit length	Ω/m
Z_0	characteristic impedance	Ω

Symbols

α	turns ratio	-
α	attenuation constant	Np/m
α	thermal coefficient of resistance	1/°C
β	phase constant	rad/m
γ	propagation constant	rad/m
Γ	reflection coefficient	-
δ	skin depth	m
Δ	change, final minus initial	-
ε	permittivity	F/m
ε_0	free-space permittivity	8.854×10^{-12} F/m
ε_r	relative permittivity	-
η	efficiency	-
θ	phase angle	rad
κ	coupling coefficient	-
μ	permeability	H/m
μ_o	free-space permeability	1.2566×10^{-6} H/m
μ_r	relative permeability	-
ξ	ratio of radii	-
ρ	resistivity	$\Omega \cdot \text{m}$
σ	conductivity	S/m
ω	armature angular speed	rad/s

Subscripts

ϕ	phase
0	zero sequence
0	characteristic
0	free space (vacuum)
0,o	initial (zero value)
1	positive sequence
1	primary
2	negative sequence
2	secondary
ab	a to b
AC	alternating current
avg	average
bc	b to c
c	controls or critical
c	core
C	capacitor
ca	c to a
Cu	copper
d	direct
DC	direct current
e	eddy current
e	equivalent
eff	effective
ext	external
f	final / frequency
fl	full load
g	generator
h	hysteresis
int	internal
l	line
l	per unit length
L	inductor

ll	line-to-line
m	motor
m	maximum
m	mutual
max	maximum
n	neutral
nl	no load
O	origin
oc	open circuit
p	phase
p	primary
ps	primary to secondary
pu	per unit
q	quadrature
R	receiving end
R	resistance
s	synchronous
s	secondary
S	sending end
sc	short circuit
sys	system
t	terminal
w	wave

Electrical Power: Part V
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COURSE INTRODUCTION

Although this is a five part course, each individual part is meant to be stand-alone should one be interested in that topic. The overall purpose of the course is to provide an overview of electric power from generation, through the various distribution systems, including the vital transformer links that change the voltage from the high voltage required for minimum losses during transmission to medium- and low-voltage for the end-users. Additionally, the transmission lines connecting the system are covered. And, finally, the rule from the National Electric Safety Code® (NESC®) that govern it all completes the overview.

Part I, Generation, the more common type of plants producing the power. The basics of alternating current and direct current generators is explained include the principles of parallel operation. Finally, energy management and power quality are covered.

Part II, Distribution Systems, covers the classification of such systems, how the common neutral is utilized, overhead and underground distribution, along with fault analysis methods.

Part III, Transformers, informs on power transformers, their ratings, voltage regulation, testing methods and parameters used to analyze both transformers and transmission lines.

Part IV, Transmission Lines, discusses the electrical parameters of such line: resistance, inductance, and capacitance. Important effects such as the skin effect and reflection are explained. This part completes with an explanation of models for each type of transmission line: short, medium, and long.

Part V, The National Electrical Safety Code, covers organization of the code and some of the multitude of requirements for the transmission of electrical power.

The information is primarily from the author's books, Refs. [A] and [B] with the NESC information from the Handbook covering the code, Ref. [C]. The coverage of the NESC does not include end-users buildings—this is covered by the NEC, Ref. [D]. Information useful in many aspects of electric engineering may be found in [E] and [F] as well as the appendices. Reference [G] has detailed descriptions of analysis techniques. Reference [H] provides detailed engineering review for Parts I through IV of this course. Reference [I] provides indepth explanation of the per-unit system often used in such engineering.

OVERVIEW OF NESC

The National Electrical Safety Code (NESC) was initiated in 1913 at the National Bureau of Standards. It is now under the sponsorship and control of the Institute of Electrical and Electronic Engineers (IEEE) and is published as a voluntary IEEE standard. The NESC (hereafter referred to as the "Safety Code") is officially endorsed by the American National Standards Institute (ANSI), and the committee responsible for the Safety Code is known as ANSI Standards Committee C2. While voluntary, the Safety Code is often adopted by each individual state, specifically by the state authority with jurisdiction over utilities.[2]

The Safety Code generally applies to "practical safeguarding of persons during the installation, operation, and maintenance of electric supply and communications lines, and associated equipment." Its general purpose is to safeguard utility persons and the general public.

The Safety Code consists of General Sections followed by four parts, all of which are further subdivided into sections and then rules. The outline of the Safety Code follows. Part numbers (single digits) and Section numbers (two digits) are given in parentheses. Rules are three digit numbers.[3]

Further, the standard numbering used by the NESC follows. For each rule, there may be up to six levels of subdivision.

Level 1: A., B., C., etc.
Level 2: 1., 2., 3., etc.
Level 3: a., b., c., etc.
Level 4: (1), (2), (3), etc.
Level 5: (a), (b), (c), etc.
Level 6: i, ii, iii, etc.

When headings for levels 1, 3, and 5 require a double letter to identify because the 26 letters of the alphabet have already been used, the following lettering sequence shall be utilized: AA., BB., CC., aa., bb., cc., (aa), (bb), (cc), etc.

[2] The Code is updated every 5 years. This course is based on the 2023 Code, which was delayed by a year.
[3] For example, the number 232B1 would indicate Part 2, Section 23, Rule 232, Paragraph B1 (using Levels 1 and 2).

General Sections

(01) Introduction to the NESC
(02) Definitions of Special Terms
(03) References
(09) Grounding

Part 1 Safety Rules for the Installation and Maintenance of Electric Supply Stations and Equipment

(10) Purpose and Scope of Rules
(11) Protective Arrangements in Electric Supply Stations
(12) Installation and Maintenance of Equipment
(13) Rotating Equipment
(14) Storage Batteries
(15) Transformers and Regulators
(16) Conductors
(17) Circuit Breakers, Reclosers, Switches, and Fuses
(18) Switchgear and Metal-Enclosed Bus
(19) Photovoltaic Generating Stations

Part 2 Safety Rules for the Installation and Maintenance of Overhead Electric Supply and Communication Lines

(20) Purpose, Scope, and Application of Rules
(21) General Requirements
(22) Relations Between Various Classes of Lines and Equipment
(23) Clearances
(24) Grades of Construction
(25) Structural Loadings for Grades B and C
(26) Strength Requirements
(27) Line Insulation

Part 3 Safety Rules for the Installation and Maintenance of Underground Electric Supply and Communication Lines

(30) Purpose, Scope, and Application of Rules
(31) General Requirements Applying to Underground Lines
(32) Underground Conduit Systems
(33) Supply Cable
(34) Cable in Underground Structures
(35) Direct Buried Cable
(36) Risers
(37) Supply Cable Terminations
(38) Equipment
(39) Installation in Tunnels

Part 4 Work Rules for the Operation of Electric Supply and Communication Lines and Equipment

(40) Purpose and Scope
(41) Supply and Communications Systems—Rules for Employers
(42) General Rules for Employees
(43) Additional Rules for Communications Employees
(44) Additional Rules for Supply Employees

Appendices[4]

A) Uniform System of Clearances
(B) Uniform Clearance Calculations for Conductors Under Ice and Wind Conditions
(C) Example Applications for Rule 250C Tables 250-2 and 250-3
(D) Determining Maximum Anticipated Per-Unit Overvoltage Factor (T) at the Worksite
(E) Bibliography
Annex 1: Metric Table and Figures
Annex 2: Letter Symbols for Units

[4] Per standard formatting, an appendix contains information integral to the main document. An appendix, annex, or a note is informative in nature. The Code Handbook [D] has an Appendix A that shows pictures explaining applications of the rules, which is helpful. The Appendices and Annexes shown here are only in the Code itself.

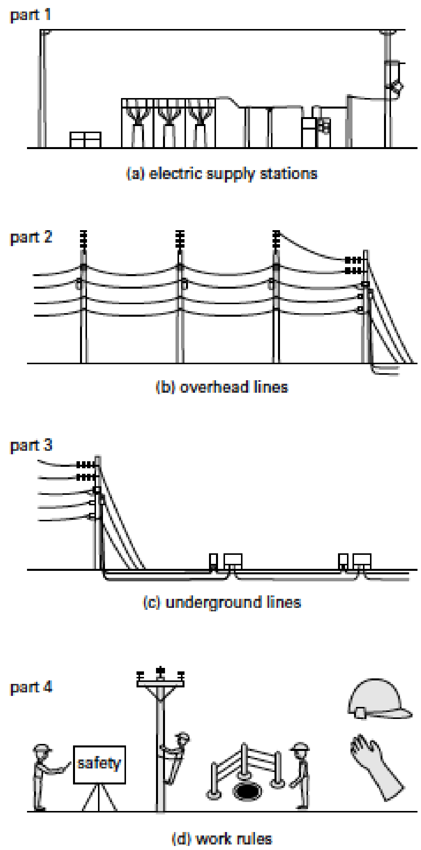

Figure 1: NESC Areas of Concern

The Safety Code parts separate into the general areas as shown in Fig. 1. In this course, numbers in brackets, if used, indicate the rule number in the Safety Code and are meant for ease in referencing the Safety Code directly. Specific limits may be found in the latest code. Though metric is the official system for the Safety Code, a mixture of customary U.S. engineering units and SI units is used.

Notable changes to the 2023 NESC[5] include:

- Significant revisions were made in Section 14 covering batteries, addressing new battery technologies, energy storage, and backup power.

[5] According to IEEE at https://standards.ieee.org/news/2023-nesc-release/.

- A new Section 19 for photovoltaic generating stations addresses general codes, location, grounding configurations, vegetation management, DC overcurrent protection, and DC conductors. These new rules accommodate large-scale solar power projects.
- All stand-alone tables for metric measurements have been removed from the main code body and moved to Annex 1. For tables that include both English and metric values, the revised Code presents numerical values in the customary “inch-foot-pound” system first and the corresponding metric values following in parentheses to help prevent misreading errors.
- In the Clearances section, as well as in the specification of the Grade of Construction, the Code further clarifies the use of non-hazardous fiber optic cables.

NESC INTRODUCTION

Section 01 of the General Sections is titled “Introduction to the National Electrical Safety Code.” Rule 010 specifies the purpose as the safeguarding of persons during installation, operation, or maintenance. The Safety Code is meant to contain the basic guidelines for safety. It covers electric power, which the Safety Code refers to as electric “supply,” lines and associated equipment, as well as communication lines and equipment. “Communications” refers to, but is not limited to, telephone and cable television.

Rule 011 covers the scope of the code. The area of coverage for the Safety Code is shown in Fig. 2. The exact demarcation between the National Electrical Code (NEC) and the NESC is shown in Fig. 3.

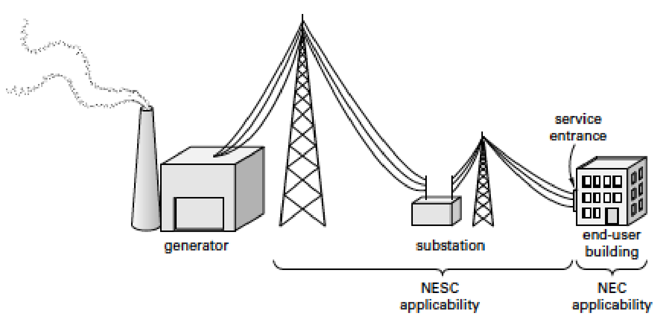

Figure 2: NESC Comparison Coverage

In addition to covering different areas of responsibility, the NESC and NEC differ as indicated in Table 1.

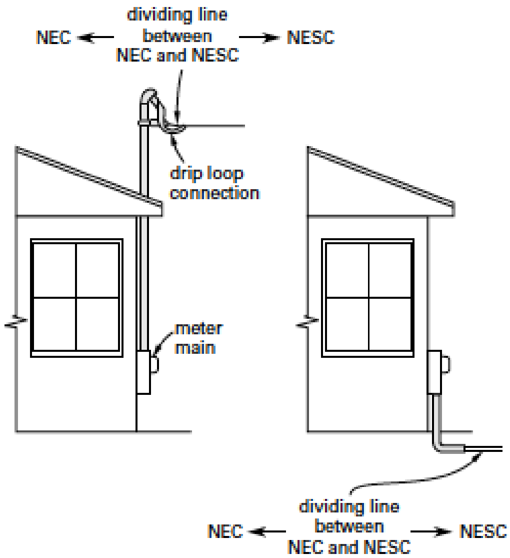

Figure 3: NEC/NESC Division of Responsibility

Table 1 NEC and NESC Comparison

NEC	NESC
published by NFPA	published by IEEE
code book for building industry	code book for utilities
legal authority by state, city, or local law	legal authority by state utility commissions
revised every 3 yr	revised every 5 yr
used by engineers and electricians	used by engineers and utility linemen

At times both the NEC and NESC will appear to apply. One such case is lighting. Per Rule 011, street and area lighting that is metered usually is covered by the NEC; whereas, lighting that is not metered and is owned, operated, and maintained by a utility is covered by the NESC. Those items covered by the NEC are typically operated and maintained by electricians; whereas, those operated and maintained by a utility are maintained by power line workers.

Rule 012 requires the use of the Safety Code. If an item or situation is not covered in the Safety Code, then “accepted good practice” is allowed. Rule 013 requires all new installations to comply with the Safety Code. Rule 014 provides the conditions for a waiver of requirements. Rule 015 defines "shall," "should," and "RECOMMENDATION."

The term "shall" indicates a rule is mandatory and must be met. The term "should" indicates a rule that is applied normally, and is practical for the given situation. The term "RECOMMENDATION" is used to indicate a rule that is desired but not mandatory. Additionally, Rule 015 specifies that "NOTES" and "EXAMPLES" are not mandatory. However, "Footnotes" carry the force of the table or rule with which they are associated. Interpretation of the scope of "RECOMMENDATION," "NOTE," and "EXCEPTION" is also provided in this rule.

Rule 017 specifies that metric units are the primary units. Customary U.S. units are shown in parentheses. Rule 017B specifies that values in the Safety Code are nominal and tolerances may exist in other standards.[6]

Rule 018 "Method of Calculation" requires rounding off to the nearest significant digit, unless otherwise specified in the rules.[7] One such example is for clearance calculations where *rounding up* is called for to ensure minimum clearance requirements are met.

SPECIAL TERMS

Section 02 of the General Sections is titled "Definitions of Special Terms." If a term is not defined in this section, then IEEE Standards Dictionary Online is to be used.[8] If the term cannot be found in either, then a standard dictionary is to be used.[9]

REFERENCES

Section 03 of the General Sections is titled "References." Any reference in this section is considered part of the Safety Code. If the reference is listed in Appendix E of the code *only,* it is

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[6] Nominal is defined as the "size for general identification" where the actual size will be approximately the same but need not be exactly the same. See Ref. [J] for a variety of engineering definitions.
[7] The rule indicates that rounding is that learned in traditional math class. Discretion is necessary for those items ending in "5". The rule used in engineering is to round up if it creates an even number and round down for an odd number. Bottom line, meet the intent of the rule. Look for words like "no less than" or "no more than" and the like.
[8] This was formally IEEE-100-2000 (7th Edition) but it now exists only online.
[9] Occasionally, rules will contain definitions.

there for information only. Appendices, Annexes, and Notes are all for information only. The relationships between References and the NESC Bibliography is shown in Figure 4.

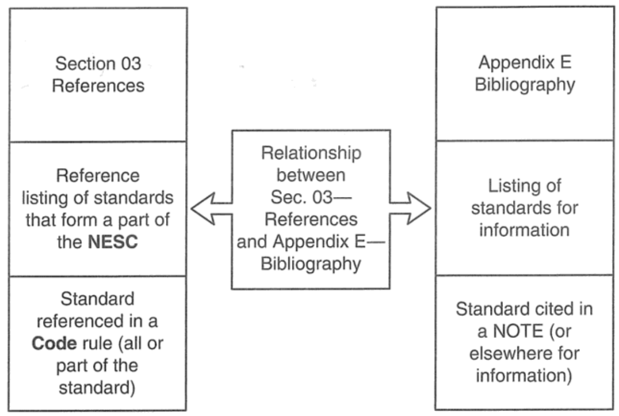

Figure 4: References vs. Bibliography
[Source: *NESC Handbook*]

GROUNDING

Section 09 of the General Sections is titled "Grounding Methods for Electric Supply and Communications Facilities." This entire section is devoted to the requirements for properly grounding electrical systems to ensure safety. A distinction is made between systems at and over 750 V and those under that value.

Rules in the grounding section require lighting loads to use wye and delta circuits that are grounded or else to use a common neutral conductor. The proper ground connections for systems of 750 V and below are shown in Fig. 5. Grounding connections are made at both the source and line (load) side of a service entrance to a building.

The ampacity of grounding conductors is also specified in this section. The main specification is that fault current of a given time duration cannot melt or damage the grounding conductor. The "given time" is determined by the time-current characteristics of the fault protective device (e.g., the fuse, recluse, relay, or breaker) and the system impedance. The ampacity comes from manufacturers' short-circuit withstand charts. If the appropriate value is not determined, the grounding conductor must be sized for the full-load continuous current of the supply transformer.

NESC PART 1

Part 1 of the Safety Code is titled “Rules for the Installation and Maintenance of Electric Supply Stations and Equipment.” This part covers the electric supply stations as shown in Fig. 1(a). Electric supply stations consist of generating stations, substations, and switch stations. The rules assume such areas are accessible to “qualified personnel” only. That is, the general public is not expected to be in the area.

Rule 110 requires enclosures for supply stations to consist of fences, screens, partitions, or walls. The electrical components within the enclosure are required to meet clearance requirements to ensure personnel are not likely to come into contact with live electrical components.

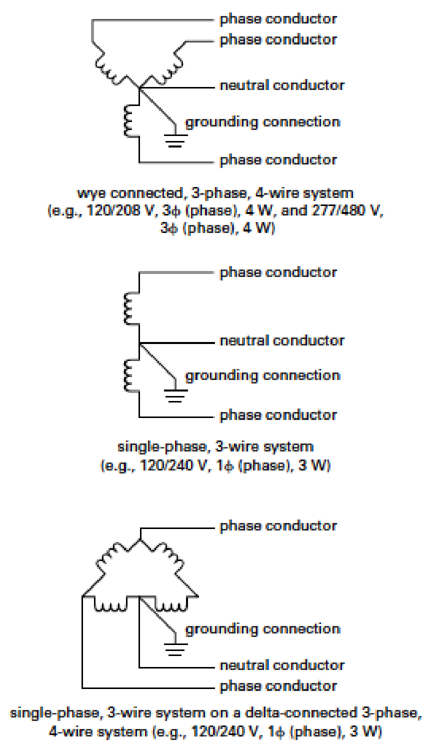

Figure 5: Allowable Ground Connections (≤750 V)

The enclosure is generally required to be 7 ft high and to limit access. Additionally, the electrical equipment inside the enclosure must have a standoff distance, called safety clearance zone, which depends on the highest voltage level in the substation. This rule requires the signage as specified in ANSI Z535. The general approach is that a warning sign is posted on the barrier. And, if the barrier is breached, a danger sign is posted internally to the enclosure.

ANSI Z535 stipulates three types of signs: caution, warning, and danger. Caution signs have a yellow background and indicate a potential hazard of minor or moderate injury or other consequence of unsafe practices. Warning signs have an orange background and indicate a potential hazard of serious injury or death. Danger signs have a red background and indicate an imminent hazard of serious injury or death.

Illumination levels are given in Rule 111, although portable lighting may be used to meet the specified levels. Rule 112 requires floors to be even and nonslip. Obstructions must be painted, marked, or posted with safety signs. Stairways with three steps do not require handrails; those with four or more steps do require such handrails.

Rule 113 requires exits to be free of obstructions. In addition, double exits are required if an accident can make a single exit inaccessible.

Rule 123 requires protective grounding in accordance with IEEE Standard 80.

Rule 124 requires live parts over 150 V to be guarded. Guarding implies a physical barrier. Additionally, if the electrical potential of a given electrical part is unknown, the vertical clearance must be at least 8 ft 6 in.

Working space, that is, horizontal clearance, is specified in Rule 125. The space required is dependent on the voltage level. The requirements differ for voltages greater than 600 V and voltages of 600 V and less. For 600 V or less, at least 7 ft of head clearance and 30 in of width are the minimum. The working spaces in NESC Table 125-1 are for exposed energized parts, and do not apply if the parts are de-energized during maintenance or servicing.

Rule 131 requires that motors do not restart automatically after a power outage if such starting creates a hazard for personnel. This means that such motors should have low-voltage protection (LVP) that requires an operator to physically restart the motor following an outage. Low-voltage release (LVR) is a protective scheme that allows automatic restart without interaction with a human operator. Such LVR schemes are allowed if warning signals and time delays are incorporated.

Rule 140 governs the installation and use of batteries. The main thrust of the rule, and associated rules, is that hydrogen accumulation must be kept below "explosive mixtures" though the code does not specify an explosive percentage. (The hydrogen percentage that is explosive is approximately 4%.) Rule 142 covers *grid storage batteries*. Grid storage batteries have large energy capacities and power delivery rates and thus are prohibited from being used in switchgear and plant battery functions/applications. This prohibition is primarily because of the fire risk in the event of battery failure.

Conductors are covered in Section 16 of Part 1, in Rules 160–164. In general, the conductors must meet four conditions as follows. Conductors must

- be suitable for the intended use
- be suitable for the environmental location in which they are used
- have a voltage rating (i.e., insulation rating) adequate for the intended use
- have an ampacity (i.e., current rating) adequate for the intended use

According to Rule 174 fuses of more than 150 V to ground, or carrying more than 60 A, must be classified as disconnecting, or be arranged to be able to disconnect from the power source, or be removed with insulated handles.

Surge arresters are common in the utility industry and are used to protect equipment from switching surges and lightning strikes. Arresters are mentioned in Section 17, Rule 177.[10] The basic requirements, however, come from IEEE Standards C62.1 and C62.11.[11]

Section 019 applies to utility scale photovoltaic systems, generally not to those installed on homes or commercial buildings. Rule 190 has a note referring one to Rule 011 to help tell the difference.

NESC PART 2

Part 2 of the Safety Code is titled "Safety Rules for the Installation and Maintenance of Overhead Electric Supply and Communication Lines." This part covers overhead lines as shown in Fig. 1(b). The requirements in Part 2 focus on spacing (center-to-center measurements) between conductors, clearances (surface-to-surface measurements), and the strength of construction.

[10] Surge arrestors were formerly in Section 19, which is now about Photovoltaic Generating Stations.
[11] Any standards mentioned "in the Rules" are a part of the NESC itself.

Accessibility for service and maintenance is a concern of this part. The accessibility issue is covered in Rule 213 and throughout Part 2 under the topics climbing space, working space, working facilities, and clearance between conductors.

A wide variety of clearances are required depending on the situation. However, two important arguments come from the sag and tension chart and the effects of weather conditions, called *loadings*, on the overhead lines. The *sag and tension chart* uses the type and temperature of the cable, the span length, and the weather conditions (including ice accumulation and wind speed) as inputs. The output is the maximum expected sag and tension on the overhead line that is then used to determine the construction grade. The sag and tension chart details are in Rule 230. The clearances required by Rule 230 vary with regions of the country, with Zones 1, 2, and 3 corresponding to weather designations in Rule 250 or heavy, medium, and light, respectively.

The standard weather conditions for U.S. areas are in Rule 250. The classification is light, medium, and heavy. The southern parts of the United States are in the light category, the northwestern and central portions are in the medium category, and the northeastern portions are in the heavy category. An example map is shown in Fig. 6.

Figure 6: Example Map for Weather Zones per Rule 250
[Source: *Science Direct*]

The resultant construction grades required are in Rules 240–243 and are Grade B (the highest grade), Grade C (the medium grade), and Grade N (the lowest grade). The strength requirements for each construction grade are in Rules 260–264.

NESC PART 3

Part 3 of the Safety Code is titled “Safety Rules for the Installation and Maintenance of Underground Electric Supply and Communication Lines.” This part covers underground installations as shown in Fig. 1(c). The requirements of Part 3 focus on underground installations for supply (power) and communications (telephone and cable television and others). There is overlap at the underground riser and overhead pole between Part 2 and Part 3.

Accessibility is a concern of this part. The accessibility issue is covered in Rule 313 and throughout Part 3 under the topics working space, working facilities, and clearance between conductors.

Definitions are in Rule 320 and are shown in Fig. 7.

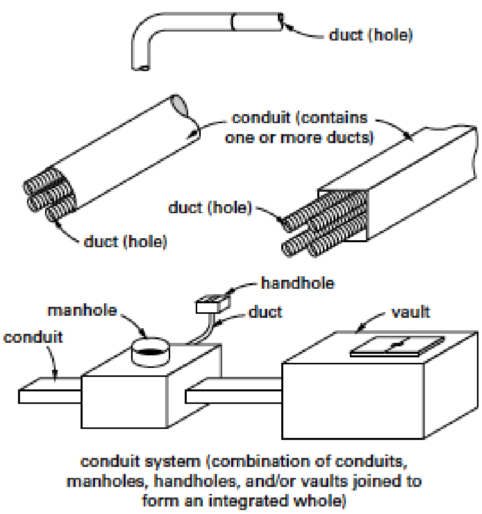

Figure 7: Underground Installation Terminology

Surprisingly, the Safety Code does not specify conduit burial depths but instead defers to “accepted good practice,” which generally means that the requirements of the NEC are applicable. Rule 320 requires that conduit running longitudinally under a road should be installed on the shoulder, and if not practical, under one lane only. This rule also requires that supply (power) and communications lines be separated as shown in Table 2.

Table 2: Underground Supply (Power) and Communication Conduit Separation Requirements

burial method	separation requirement (in)
concrete	3
masonry	4
tamped earth	12

Manhole dimensions and requirements are in Rule 323. Cable separation requirements in manholes and vaults are covered in Rule 341. Rule 341 requires communications cables to be a minimum distance from supply (power) cables depending on their voltage as given in Table 3.

Table 3: Supply (Power) and Communication Cable Separation in Joint-Use Manholes and Vaults

supply cable phase-to-phase voltage (V)	communication cable minimum separation (in)
0–15,000	6
15,001–50,000	9
50,001–120,000	12
120,001 and greater	24

The Safety Code does contain burial (depth) requirements for directly buried (that is, non-conduit encased) supply (power) cables, but not communication cables. These depth requirements are shown in Fig. 8(a), whose source is Rule 352. The depth varies with the voltage and is measured surface to surface and not center to center. Nevertheless, communications cables must meet the general burial requirements of Rule 352. Directly buried lighting cable is an exception as is shown in Fig. 8(b).

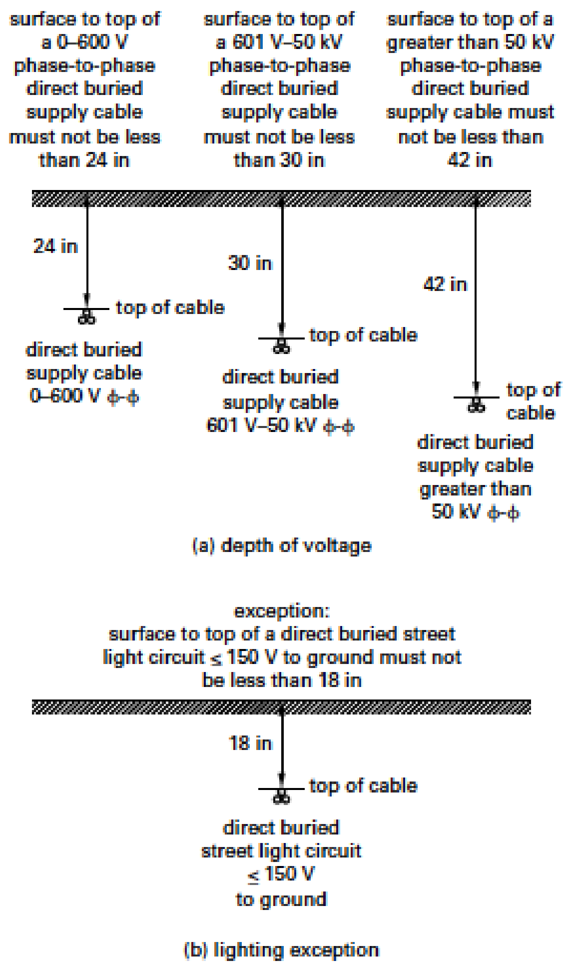

Figure 8: Underground Installation Depth (Burial) Requirements

Rules 353 and 354 are similar. Both levy radial separation requirements from underground structures, including sewer, water, natural gas, fuel, and steam lines. These rules also apply to separation from building foundations. Rule 353 covers the specifications for 12 in or greater radial separation. If the 12 in separation cannot be maintained, Rule 354 applies or the cables must be installed in a conduit system, in which case Rule 320 (covered earlier) would apply. The intent of Rule 353 is to allow for maintenance on either system without interference with the other. The intent of Rule 354 is to prevent interference between supply (power) and communication cables.

Risers bring underground cabling to the vault or pole. Riser requirements are in Rules 360–363. The supply cable terminations located in the same area are covered by Rules 370–374. The location of equipment, both on the surface and in vaults is covered in Section 38, Rules 380–385. Many of the separation distances are not specified in Section 38, instead the Safety Code defers to accepted good practice. Here again, the NEC provides a guide to much of that good practice. The Safety Code does require that supply and communications equipment be located horizontally at least 4 ft from fire hydrants, though 3 ft is allowed where conditions do not permit the 4 ft separation.

NESC PART 4

Part 4 of the Safety Code is titled "Work Rules for the Operation of Electric Supply and Communications Lines and Equipment." This part covers work rules, as indicated in Fig. 1(d). Part 4 focuses on practical *work rules* designed to safeguard both the employees performing the work and the general public. The work rules of the Safety Code have been coordinated with Occupation Safety and Health Administration (OSHA) regulations related to electric supply and communications systems.

SUMMARY

The NESC contains a great amount of detailed information. This course will hopefully give the engineer the idea of where to look. Beyond that, this course is meant to bring to the fore in an engineer's mind that a given situation may require the application of NESC Rules. For those dealing with such situations daily, I would recommend the *IEEE NESC Handbook* which uses the exact wording from the Code as well as explanatory commentary. A copy of the Code itself from IEEE is also useful.[12]

All the best in your engineering endeavors in making the world a better place.

[12] This author does not receive any compensation or the like from these works.

COURSE REFERENCES

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Appendix A: Equivalent Units Of Derived And Common SI Units

Symbol	Equivalent Units			
A	C/s	W/V	V/W	J/(s×V)
C	A×s	J/V	(N×m)/V	V×F
F	C/V	C^2/J	s/W	(A×s)/V
F/m	C/(V×m)	C^2/(J×m)	C^2/(N×m^2)	s/(Ω×m)
H	W/A	(V×s)/A	Ω×s	(T×m^2)/A
Hz	1/s	s^{-1}	cycles/s	radians/(2p×s)
J	N×m	V×C	W×s	(kg×m^2)/s^2
m^2/s^2	J/kg	(N×m)/kg	(V×C)/kg	(C×m^2)/(A×s^3)
N	J/m	(V×C)/m	(W×C)/(A×m)	(kg×m)/s^2
N/A^2	Wb/(N×m^2)	(V×s)/(N×m^2)	T/N	1/(A×m)
Pa	N/m^2	J/m^3	(W×s)/m^3	kg/(m×s^2)
W	V/A	W/A^2	V^2/W	(kg×m^2)/(A^2×s^3)
S	A/V	1/W	A^2/W	(A^2×s^3)/(kg×m^2)
T	Wb/m^2	N/(A×m)	(N×s)/(C×m)	kg/(A×s^2)
V	J/C	W/A	C/F	(kg×m^2)/(A×s^3)
V/m	N/C	W/(A×m)	J/(A×m×s)	(kg×m)/(A×s^3)
W	J/s	V×A	V^2/W	(kg×m^2)/s^3
Wb	V×s	H×A	T/m^2	(kg×m^2)/(A×s^2)

Appendix B: Physical Constants[1]

Quantity	Symbol	US Customary	SI Units
Charge			
electron	e		- 1.6022´ 10^{-19} C
proton	p		+1.6022´ 10^{-19} C
Density			
air [STP][32°F, (0°C)]		0.0805 lbm/ft^3	1.29 kg/m^3
air [70°F, (20°C), 1 atm]		0.0749 lbm/ft^3	1.20 kg/m^3
sea water		64 lbm/ft^3	1025 kg/m^3
water [mean]		62.4 lbm/ft^3	1000 kg/m^3
Distance			
Earth radius[2]	⊕	2.09´ 10^{7} ft	6.370´ 10^{6} m
Earth-Moon separation[2]	⊕☾	1.26´ 10^{9} ft	3.84´ 10^{8} m
Earth-Sun separtion[2]	⊕⊙	4.89´ 10^{11} ft	1.49´ 10^{11} m
Moon radius[2]	☾	5.71´ 10^{6} ft	1.74´ 10^{6} m
Sun radius[2]	⊙	2.28´ 10^{9} ft	6.96´ 10^{8} m
first Bohr radius	a_0	1.736´ 10^{-10} ft	5.292´ 10^{-11} m
Gravitational Acceleration			
Earth [mean]	g	32.174 (32.2) ft/sec^2	9.8067 (9.81) m/s^2
Mass			
atomic mass unit	∝ or $m_{\propto}$ $\frac{1}{12}m\left({}^{12}C\right)$	3.66´ 10^{-27} lbm	1.6606´ 10^{27} kg or 10^{-3} kg mol^{-1} / N_A
Earth[2]	⊕	4.11´ 10^{23} slugs	6.00´ 10^{24} kg
Earth [customary U.S.][2]	⊕	1.32´ 10^{25} lbm	-
Moon[2]	☾	1.623´ 10^{23} lbm	7.36´ 10^{22} kg
Sun[2]	⊙	4.387´ 10^{30} lbm	1.99´ 10^{30} kg
electron rest mass	m_e	2.008´ 10^{-30} lbm	9.109´ 10^{-31} kg
neutron rest mass	m_n	3.693´ 10^{-27} lbm	1.675´ 10^{-27} kg
proton rest mass	m_p	3.688´ 10^{-27} lbm	1.672´ 10^{-27} kg
Pressure			
atmospheric		14.696 (14.7) lbf/in^2	1.0133´ 10^{5} Pa
Temperature			
standard		32 F (492 R)	0 C (273 K)
absolute zero		- 459.67 F (0 R)	- 273.16 C (0 K)
Velocity[3]			
Earth escape		3.67´ 10^{4} ft/sec	1.12´ 10^{4} m/s
light (vacuum)	c, c_0	9.84´ 10^{8} ft/sec	2.9979 (3.00) ´ 10^{8} m/s
sound [air, STP]	a	1090 ft/sec	331 m/s

Table Notes

1. Units come from a variety of sources, but primarily from the Handbook of Chemistry and Physics, The Standard Handbook for Aeronautical and Astronautical Engineers, and the Electrical Engineering Reference Manual for the PE Exam. See also the NIST website at https://pml.nist.gov/cuu/Constants/.
2. Symbols shown for the solar system are those used by NASA. See https://science.nasa.gov/resource/solar-system-symbols/.
3. Velocity technically is a vector. It has direction.

Appendix C: Fundamental Constants

Quantity	Symbols	US Customary	SI Units
Avogadro's number	N_A, L		6.022×10^{23} mol^{-1}
Bohr magneton	μ_B		9.2732×10^{-24} J/T
Boltzmann constant	k	5.65×10^{-24} ft-lbf / R	1.3805×10^{-23} J/T
electron volt: $\left(\frac{e}{C}\right)$ J	eV		1.602×10^{-19} J
Faraday constant, $N_A e$	F		96485 C/mol
fine structure constant, inverse α^{-1}	α α^{-1}		7.297×10^{-3} (≈1/137) 137.035
gravitational constant	g_c	32.174 lbm-ft/lbf-sec^2	
Newtonian gravitational constant	G	3.44×10^{-8} ft^4 / lbf-sec^4	6.672×10^{-11} N·m^2 / kg^2
nuclear magneton	μ_N		5.050×10^{-27} J/T
permeability of a vacuum	μ_0		1.2566×10^{-6} N/A^2 (H/m)
permittivity of a vacuum, electric constant $1/\mu_0 c^2$	ε_0		8.854×10^{-12} C^2 / N·m^2 (F/m)
Planck's constant	h		6.6256×10^{-34} J·s
Planck's constant: h/2π			1.0546×10^{-34} J·s
Rydberg constant	R_∞		1.097×10^{7} m^{-1}
specific gas constant, air	R	53.3 ft-lbf/lbm- R	287 J/kg·K
Stefan-Boltzmann constant		1.71×10^{-9} BTU/ft^2-hr-°R^4	5.670×10^{-8} W/m^2·K^4
triple point, water		32.02 F, 0.0888 psia	0.01109 C, 0.6123 kPa
universal gas constant	R*	1545 ft-lbf/lbmol- R 1.986 BTU/lbmol- R	8314 J/kmol·K

Table Notes

1. Units come from a variety of sources, but primarily from the Handbook of Chemistry and Physics, The Standard Handbook for Aeronautical and Astronautical Engineers, and the Electrical Engineering Reference Manual for the PE Exam. See also the NIST website at https://pml.nist.gov/cuu/Constants/. The unit in Volume of “lbmol” is an actual unit, not a misspelling.

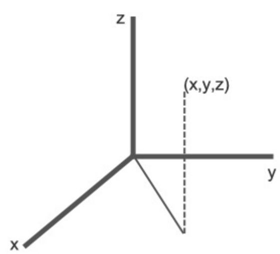
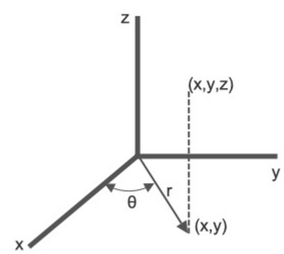
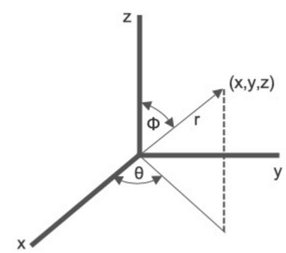
Appendix D: Mathematical Constants

Quantity	Symbol	Value
Archimedes' constant (pi)	p	3.1415926536
base of natural logs	*e*	2.7182818285
Euler's constant	*C* or t	0.5772156649

Appendix E: The Greek Alphabet

A	*a*	alpha	N	*u*	nu
B	*b*	beta	X	x	xi
G	*g*	gamma	O	*o*	omicron
D	*d*	delta	P	*p*	pi
E	*e*	epsilon	R	*r*	rho
Z	z	zeta	S	*s*	sigma
H	*h*	eta	T	*t*	tau
Q	*q*	theta	ϒ	*u*	upsilon
I	i	iota	F	*f*	phi
K	*k*	kappa	C	*c*	chi
L	*l*	lambda	Y	*y*	psi
M	*m*	mu	W	*w*	omega

Appendix F: Coordinate Systems & Related Operations

Mathematical Operations	Rectangular Coordinates	Cylindrical Coordinates	Spherical Coordinates
Conversion to Rectangular Coordinants	 $x = x$ $y = y$ $z = z$	 $x = r\cos\theta$ $y = r\sin\theta$ $z = z$	 $x = r\sin\phi\cos\theta$ $y = r\sin\phi\sin\theta$ $z = r\cos\phi$
Gradient	$\nabla f = \frac{\partial f}{\partial x}\mathbf{i} + \frac{\partial f}{\partial y}\mathbf{j} + \frac{\partial f}{\partial z}\mathbf{k}$	$\nabla f = \frac{\partial f}{\partial r}\mathbf{r} + \frac{1}{r}\frac{\partial f}{\partial \theta}\boldsymbol{\theta} + \frac{\partial f}{\partial z}\mathbf{k}$	$\nabla f = \frac{\partial f}{\partial r}\mathbf{r} + \frac{1}{r}\frac{\partial f}{\partial \phi}\boldsymbol{\phi} + \frac{1}{r\sin\theta}\frac{\partial f}{\partial \theta}\boldsymbol{\theta}$
Divergence	$\nabla \cdot \mathbf{A} = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}$	$\nabla \cdot \mathbf{A} = \frac{1}{r}\frac{\partial (rA_r)}{\partial r} + \frac{1}{r}\frac{\partial A_\theta}{\partial \theta} + \frac{\partial A_z}{\partial z}$	$\nabla \cdot \mathbf{A} = \frac{1}{r^2}\frac{\partial (r^2 A_r)}{\partial r} + \frac{1}{r\sin\phi}\frac{\partial (A_\phi \sin\phi)}{\partial \phi} + \frac{1}{r\sin\phi}\frac{\partial A_\theta}{\partial \theta}$
Curl	$\nabla \times \mathbf{A} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ A_x & A_y & A_z \end{vmatrix}$	$\nabla \times \mathbf{A} = \begin{vmatrix} \frac{1}{r}\mathbf{r} & \boldsymbol{\theta} & \frac{1}{r}\mathbf{k} \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \theta} & \frac{\partial}{\partial z} \\ A_r & A_\theta & A_z \end{vmatrix}$	$\nabla \times \mathbf{A} = \begin{vmatrix} \frac{1}{r^2\sin\theta}\mathbf{r} & \frac{1}{r^2\sin\theta}\boldsymbol{\phi} & \frac{1}{r}\theta \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \phi} & \frac{\partial}{\partial \theta} \\ A_r & rA_\phi & rA\theta A_\phi \end{vmatrix}$
Laplacian	$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} + \frac{\partial^2 f}{\partial z^2}$	$\nabla^2 f = \frac{1}{r}\frac{\partial r}{\partial r}\left(r\frac{\partial f}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 f}{\partial \theta^2} + \frac{\partial^2 f}{\partial z^2}$	$\nabla^2 f = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial f}{\partial r}\right) + \frac{1}{r^2\sin\phi}\frac{\partial}{\partial \phi}\left(\sin\phi\frac{\partial f}{\partial \phi}\right) + \frac{1}{r^2\sin^2\phi}\left(\frac{\partial^2 f}{\partial \theta^2}\right)$

