

Hard-to-Find Information on Distribution Systems Part II - The New Millennium

- Reliability
- Distributed Resources
- Decibels
- Equipment Loading
- Modern Physics
- Communications
- Faults and Inrush
- Custom Power Devices
- Cost of Interruption
- Cost of Sectionalizing Equipment
- Maintenance
- Major Event
- Line Charging
- Overcurrent



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Hard-to-Find... Part II

I. Introduction

Since Part I was a huge success, I decided to write Part II to address issues I'm seeing as a result of de-regulation. As usual, many of the topics are completely unrelated and it is questionable if they have anything to do with the major theme. They are simply things that I see from time to time that keep cropping up and I forget where the reference material I found on that topic might be. So, I put them here!!!!

As usual, nothing in this document is verifiable or guaranteed. I have tried to find good sources for the majority of this material. Personally, I only write what I believe and try very hard to make it correct, as well as useful

Finally, a note to the "New Millenium Engineer": *Computer programs are neat but understanding stuff is a lot better!!!!*

II. Contents

Part II is meant to supplement the original document. Part I is the "blue collar" stuff that makes the traditional distribution engineer impossible to replace. Part II addresses some old issues (that needed some updating) and some new issues (that have become important in this de-regulated environment). Anyway, I hope they are some use to you. **Some of the topics covered are:**

- *Distributed Resources*
- *Reliability*
- *Modern Physics*
- *Communications*
- *Custom Power*
- *Maintenance*
- *Decibels*
- *Computer Jargon 101*
- *Equipment Loading*
- *Cost of Interruption*

III. Distributed Resources

• Interesting Points

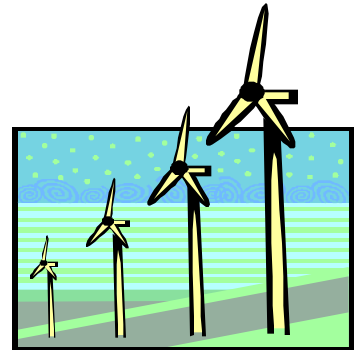
- **Fuel cells** need to be replaced every 5 years
- Gas fire combined **cycle plants** have efficiencies approaching 60%
- Niche markets for DG may approach 5% of new capacity
- **Microturbines** range from 25 kW to approximately 50 kW. The early models operated for about 2000 hours before being pulled from service.
- Microturbine efficiency is about 20 to 30%. They lose efficiency due to size and the need to compress gas. The larger units approach 40%. Some spin at 96,000 rpm.
- **Fuel cells** benefit from modularity, quiet operation, efficiency, and low pollution. Most fuel cells require an external reforming device to produce hydrogen for the stack. Efficiency of the direct fuel cell is about 50 to 55% while with a reformer is about 35% to 40%. Availability is considered good at 98% (This translates into about 7 days out of service per

year compared to most US customers seeing only 2 hours out per year). Fuel cells need to be derated by 50% after less than a year (4000 hours).

- **PV** - Not a serious option
- **Wind** - done fairly well but suffers from low capacity and mechanical problems.
- **Aeroderivative Gas Turbines** offer efficiencies of more than 40% and are proven and reliable.
- **Reciprocating Engines** – Durable, reliable, low cost and proven. Some models push efficiencies of 45%. Emissions are a concern but solvable. Water injection, used by Caterpillar to showed reductions in pollution of as much as 50%.

- **DR Efficiencies**

- Gas fired combined cycle – 60%
- Microturbines – 20% to 40%
- Fuel Cells – 35% to 55% (de-rate by 50% after 4000 hours)
- Aero-derivative Gas Turbines - 40%
- Reciprocating Engines – 45%



- **Technical Specifications**

Disconnect from utility:

- Within 6 cycles if voltage falls below 50%
- Within 2 seconds if voltage exceeds $\pm 3.7\%$ per unit
- Within 6 cycles if frequency if frequency raises above 60.3 Hz or falls below 59.3 Hz
- Inverter should not inject dc current in excess of 0.5% of full rated output
- Must disconnect in 10 cycles for potential “islanding” situation.

- **DR Costs**

Wind Systems	\$2000 per peak kW
Fuel Cells	\$3500 per kW
Solar (home, installed)	\$62,000 per kW
Solar panels	\$600 per kW
Batteries	\$100 per kW
Backup Generator	\$300 per kW
Inverter	\$600 per kW
UPS	\$1500 per kW
Motor/Generator	\$400 per kW
SMES	\$250 per kW
Capacitor	\$50 per kW
Flywheel	\$300 per kW
Microturbines	\$600 per kW
Reciprocating Engine	\$500 per kW

Exam your DG options closely. Mistakes could be costly!!



IV. Reliability

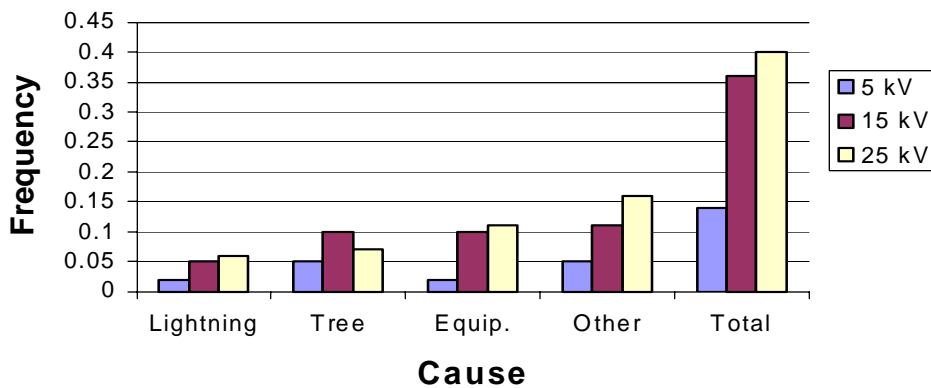
1. Typical Equipment Failure Rates

Cable Primary	.03
Cable Secondary	.11
Switch (Loop)	.05
Elbow	.0067
Splice	.0068
Fuse (transformer)	.005
Circuit Breaker	.0066
Bus	.22
Station Transformer	.02
Overhead Line	.2
Distribution Transformer	.005
Lateral Cable	.1

3. Effect of Major Events Indices

YEAR	Major Event Included			Major Events Excluded		
	SAIDI	SAIFI	MAIFI	SAIDI	SAIFI	MAIFI
1990	202	2.3	1.6	145	1.8	1.4
1991	360	2.4	1.7	143	1.8	1.5
1992	225	1.9	1.5	150	1.7	1.4
1993	161	1.7	1.4	151	1.6	1.2
1994	153	1.7	1.3	149	1.6	1.1
1995	187	2.8	2.3	145	1.5	1.4
1996	168	1.9	1.6	147	1.6	1.2
1997	560	2.8	1.8	166	1.8	2.4
1998	230	2.4	2	140	1.7	1.7

2. Primary Outage Rates



4. Indice Definitions

SAIFI [system average interruption frequency index (sustained interruptions)]. The system average interruptions frequency index is designed to give information about the average frequency of sustained interruptions per customer over a predefined area. In words, the definition is:

$$SAIFI = \frac{\text{total number of customer interruptions}}{\text{total number of customers served}}$$

To calculate the index, use the following equation:

$$SAIFI = \frac{\sum N_i}{N_T}$$

SAIDI (system average interruption duration index). This index is commonly referred to as Customer Minutes of Interruption or Customer Hours, and is designed to provide information about the average time the customers are interrupted. In words, the definition is:

$$\frac{\sum \text{customer interruption durations}}{\text{total number of customers served}}$$

To calculate the index, use the following equation:

$$SAIDI = \frac{\sum r_i N_i}{N_T}$$

CAIDI (customer average interruption duration index). CAIDI represents the average time required to restore service to the average customer per sustained interruption. In words, the definition is:

$$CAIDI = \frac{\sum \text{customer interruption durations}}{\text{total number of customers interruptions}}$$

To calculate the index, use the following equation:

$$CAIDI = \frac{\sum r_i N_i}{\sum N_i} = \frac{SAIDI}{SAIFI}$$

Values of these indices vary widely depending on many factors, including climate (snow, wind,

lightning, etc.), system design (radical, looped, primary selective, secondary network, etc.), and load density (urban, suburban and rural). Typical values seen by utilities in the United States are:

SAIDI	SAIFI	CAIDI
110 min/yr	1.4 int/yr	79 min/yr

Some utilities are already measuring indices to reflect system disturbances, other than interruptions, that cause sensitive loads to misoperate. One of these, the momentary average interruption event frequency index, (MAIFI) is an index to record momentary outages caused by successful reclosing operations of the feeder breaker or line recloser. This index is very similar to SAIFI, but it tracks the average frequency of momentary interruption events. In words, the definition is:

$$MAIFI_E = \frac{\text{Total number of customer momentary interruption events}}{\text{Total number of customers served}}$$

To calculate the index, use the following equation:

$$MAIFI_e = \frac{\sum ID_e N_i}{N_T}$$

(Typical value for MAIFI is 6 interruptions per year).

5. Voltage Sags

$$SARFI_{\%V} = \frac{\sum N_i}{N_T}$$

where %V = rms voltage threshold 140, 120, 110, 90, 80, 70, 50, 10

N_i = number of customers experiencing rms < % V for variation i (rms > % V for % V > 100)

N_T = Total number of system customers

Typical values of SARFI:

SARFI 90 – 50

SARFI 70 – 20

SARFI 50 – 10

SARFI 10 – 5

Typical number of sags for all causes = 350

Typical number of momentaries for all causes = 10

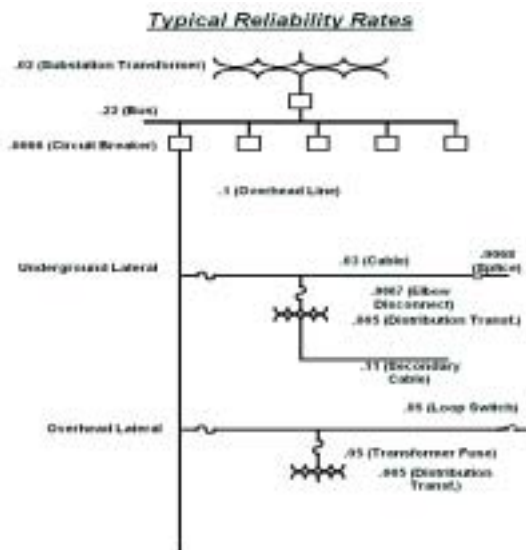
6. Interruption Survey

- 65% report information to regulators
- 37% calculate MAIFI
- 83% feel indices should be calculated separately from generation and transmission
- 76% feel that scheduled interruptions should be calculated separately
- 70% have major event classifications
- 94% use computer programs to generate reliability indices

7. Loading

Increased loading of equipment will take life out of the equipment and could ultimately contribute to equipment failure. The following are some important considerations when overloading equipment, especially transformers:

- Insulation life of a transformer is when it loses 50% of its insulation strength.
- The temperature of top oil should never exceed 110C for transformers having a 65C average winding rise.
- Peak short duration loading should never exceed 200%.
- Hot spot should never exceed 180C for 65C systems due to the possibility of free bubbles that could weaken insulation strength. Under normal conditions, hot spot should not exceed 130C.
- Transformers should be operated for normal life expectancy.
- A 2.5% loss of life per day may be acceptable in the event of an emergency.



V. Modern Physics

Too often, distribution engineers are told they're behind the times. So I've included a few tidbits so you can impress your friends with your range of knowledge. You never know when you might need the following:

- **Big Bang** – The progression of the “Big Bang” is considered to be as follows:
 - 0 to 10^{-43} seconds - ??????????
 - 10^{-43} seconds – Quantum Gravity
 - 10^{-12} seconds – Quantum Soup
 - 10^{-16} seconds – Protons and Neutrons form
 - 1 minute – Helium formed
 - 5 minutes – Helium complete
 - 500,000 years – Atoms form – Background radiation (COBE)

- **Forces** – There are now considered to be 3 forces which are as follows:
 - Gravity
 - Electro-weak
 - Strong (color)
- **Color Charge** – The so called “color force” does not fall off with distance and is as follows:
 - Red
 - Green
 - Blue
- **Quarks** – Quarks are the fundamental particles (called fermions) of nature. There are 6:
 - Up Quark
 - Down Quark
 - Charmed Quark
 - Strange Quark
 - Top Quark
 - Bottom Quark

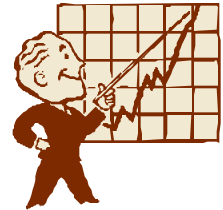


VI. Loading

Probably no area of distribution engineering causes more confusion than does loading. Reading the standards does not seem to help much since everyone appears to have their own interpretation. Manufacturers of equipment are very conservative since they really never know how the user will actually put the product to use so they must expect the worst. On the other hand, many users seem to take the approach that since it didn't fail last year with traditional overloading values, it won't fail this year either. In fact, it won't fail until after retirement. Heck! "Save a Buck and Get a Promotion". The author of this document is not a psychology major and frankly has no idea of what the thinking was when much of the following was produced. The material that follows, however, was taken from sources with excellent reputation. Use it with caution!

1. Transformer Loading Basics

- All modern transformers have insulation systems designed for operation at 65C average winding temperature and 80C hottest-spot winding rise over ambient in an average ambient of 30C. This means:
 - ***65C average winding rise + 30C ambient = 95C average winding temperature***
 - ***80C hottest spot rise + 30C ambient = 110C hottest spot***
- (OLD system: 55C winding rise + 30C ambient = 85C average winding



temperature

$$65\text{C hottest spot} + 30\text{C ambient} = \mathbf{95\text{C hottest spot}}$$

- Notice that 95C is the average winding temperature for the new insulation system and the hottest spot for the old. A source of immense confusion for many of us.
- The temperature of the top oil should not exceed 100C. Obviously, top oil temperature is always less than hottest spot.
- The maximum hot-spot temperature should not exceed 150C for a 55C rise transformer or 180C for a 65C rise transformer.
- **Peak .5 hour loading should not exceed 200%**
- The conditions of 30C ambient temperature and 100% load factor establish the basis of transformer ratings.
- The ability of the transformer to carry more than nameplate rating under certain conditions without exceeding 95C is basically due to the fact that top oil temperature does not instantaneously follow changes in transformer load due to thermal storage.
- **An average loss of life of 1% per year** (or 5% in any emergency) incurred during emergency operations is considered reasonable.

- Most companies do not allow normal daily peaks to exceed the permissible load for normal life expectancy.
- The firm capacity is usually the load that the substation can carry with one supply line or one transformer out of service.
- **“Emergency 24 Hour Firm Capacity”** usually means a loss of life of 1% but is sometimes as much as 5% or 6%.
- The following measures can be used for emergency conditions lasting more than 24 hours:
 - Portable fans
 - Water spray
 - Interconnect cooling equipment of FOA units.
 - Use transformer thermal relays to drop certain loads.

2. Examples of Substation Transformer Loading Limits

The following is an example of maximum temperature limits via the IEEE for a 65C rise transformer:

	IEEE Normal Life Expectancy
Top Oil Temperature	105C
Hotspot Temperature	120C

This next example shows the loading practice of various utilities for substation transformers:

Normal Conditions	Utility A	Utility B	Utility C	Utility D	Utility E	Utility F	Utility G
Top Oil	95	110	95	95	95	110	110
Hotspot	125	130	120	110	120	140	120
Emergency							
Top Oil	110	110	110	110	110	110	110
Hot Spot	140	140	140	130	140	140	140

What happens when the hotspot is raised from 125C to 130C? This is shown as follows:

Maximum Hotspot	% Loss of Life, Annual
125	0.3366
130	0.5372

An example of the **effect of load cycle** (3 hour peak with 70% pre-load for 13 hours and 45% load for 8 hours) and ambient on transformer capability via the ANSI guide is shown below:

Transformer Type	Peak Load for Normal Life Expectancy		Emergency Peak Load with 24-Hour Loss of Life	
	10C Ambient	30C Ambient	0.25%	1.0%
20000 - OA	30,000	24,200	28,400	32,000
15000/2000 – OA/FA	28,700	23,800	27,500	30,700
12000/16000/20000 – OA/FA/FOA	27,500	23,200	26,800	29,700
20000 - FOA	27,500	23,200	26,800	29,700

The following is the effect on transformer ratings for various limits of **top oil temperature**:

	MVA	Top Oil Temperature
Normal Rating	50	95C
New Rating	55	105C
Emergency Rating	59	110C

3. Distribution Transformers

The loading of distribution transformers varies more widely than substation units. Some utilities try to never exceed the loading of the transformer nameplate. Others, particularly those using TLM, greatly overload smaller distribution transformers with no apparent increase in failure rates. An example of one utilities practice is as follows:

KVA	Padmounted		Submersible	
	Install Range	Removal Point	Install Range	Removal Point
25	0-40	55	0-34	42
50	41-69	88	35-64	79
75	70-105	122	65-112	112
100	106-139	139	113-141	141

4. Ampacity of Overhead Conductors

In part 1 of the Hard-to-Find, I listed some conservative ratings for conductors per the manufacturer. The table below shows the rating of conductors via a typical utility:

Conductor Size	ACSR		All Aluminum	
	Normal	Emergency	Normal	Emergency
1/0	319	331	318	334
2/0	365	379	369	388
3/0	420	435	528	450
4/0	479	496	497	523
267	612	641	576	606
336	711	745	671	705
397	791	830	747	786

5. Emergency Ratings of Equipment

The following are some typical 2 hour overload ratings of various substation equipment. Use at your own risk:

Station Transformer	140%
Current Transformer	125%
Breakers	110%
Reactors	140%
Disconnects	110%
Regulators	150%

6. Miscellaneous Loading Information

The following is some miscellaneous loading information and thoughts from a number of actual utilities:

a. Commercial and Industrial Transformer Loading

Load Factor %	Transformer Load Limit
0-64	130%
65-74	125%
75-100	120%

b. Demand Factor

Lights – 50%
 Air Conditioning – 70%
 Major Appliances – 40%

c. Transformer Loading

- Distribution transformer life is in excess of 5 times present guide levels
- Distribution guide shows that life expectancy is about 500,000 hours for 100C hottest-spot operation, compared to 200,000 hours for a power transformer. Same insulation system.
- Using present loading guides, only 2.5% of power transformer thermal life is used up after 15 years.
- Results of one analysis showed that the transition from acceptable to unacceptable risk (approximately an order of magnitude) was accompanied (by this utility) by only a 8.5% investment savings and a 12% increase in transformer loading.
- Application of transformers in *excess of normal loading* can cause:

- Evolution of **free gas** from insulation of winding and lead conductors.
- Evolution of free gas from insulation adjacent to metallic structural parts linked by magnetic flux produced by winding or lead currents may also reduce dielectric strength.
- Operation at high temperatures will cause **reduced mechanical strength** of both conductor and structural insulation.
- Thermal expansion of conductors, insulation materials, or structural parts at high temperature may result in permanent **deformations** that could contribute to mechanical or dielectric failures.
- **Pressure build-up in bushings** for currents above rating could result in leaking gaskets, loss of oil, and ultimate dielectric failure.
- **Increased resistance in the contacts** of tap changers can result from a build-up of oil decomposition products in a very localized high temperature region.
- Reactors and current transformers are also at risk.
- **Oil expansion** could become greater than the holding capacity of the tank.
- ***Aging or deterioration of insulation*** is a time function of temperature, moisture content, and oxygen content. With modern oil preservation systems, the moisture and oxygen contributions to insulation deterioration can be minimized, leaving insulation temperature as the controlling parameter.
- Distribution and power transformer model tests indicate that the ***normal life expectancy*** at a continuous hottest-spot temperature of 110C is **20.55 years**.
- Input into ***a transformer loading program*** should be:
 - Transformer characteristics (loss ratio, top-oil rise, hottest spot rise, total loss, gallons of oil, weight of tank and fittings).
 - Ambient temperatures
 - Initial continuous load
 - Peak load durations and the specified daily percent loss of life
 - Repetitive 24 hour load cycle if desired
- ***Maximum permitted loading*** is 200% for power transformer and 300% for a distribution transformer.
- Suggested limits of ***loading for distribution transformers*** are:
 - Top-oil – 120C
 - Hottest - spot – 200C
 - Short time (.5 hour) – 300%
- Suggested ***limits for power transformers*** are:
 - Top-oil – 100C
 - Hottest-spot – 180C
 - Maximum loading – 200%

- Overload limits for *coordination of bushings* with transformers is:
 - Ambient air – 40C maximum
 - Transformer top-oil – 110C maximum
 - Maximum current – 2 times bushing rating
 - Bushing insulation hottest-spot – 150C maximum
- Current rating for the *LTC* are:
 - Temperature rise limit of 20C for any current carrying contact in oil when carrying 1.2 times the maximum rated current of the LTC
 - Capable of 40 breaking operations at twice rate current and KVA
- Planned *loading beyond nameplate* rating defines a condition wherein a transformer is so loaded that its hottest-spot temperature is in the temperature range of 120C to 130C.
- Long term *emergency loading* defines a condition wherein a power transformer is so loaded that its hottest-spot temperature is in the temperature range of 120C to 140C.
- The *principle gases* found dissolved in the mineral oil of a transformer are:
 - **Nitrogen:** from external atmosphere or from gas blanket over the free surface of the oil
 - **Oxygen:** from external atmosphere
 - **Water:** from moisture absorbed in cellulose insulation or from decomposition of the cellulose
 - **Carbon dioxide:** from thermal decomposition of cellulose insulation
 - **Carbon monoxide:** from thermal decomposition of cellulose insulation
 - **Other Gases:** may be present in very small amounts (e.g. acetylene) as a result of oil or insulation decomposition by overheated metal, partial discharge, arcing, etc. These are very important in any analysis of transformers, which may be in the process of failing.
- **Moisture** affects insulation strength, power factor, aging, losses and the mechanical strength of the insulation. Bubbles can form at 140C which enhance the chances of partial discharge and the eventual breakdown of the insulation as they rise to the top of the insulation.. If a transformer is to be overloaded, it is important to know the moisture content of the insulation, especially if it's an older transformer. Bubbles evolve fast so temperature is important to bubbles formation but not time at that temperature. Transformer insulation with 3.5% moisture content should not be operated above nameplate for a hottest spot of 120C. Tests have shown that the use of circulated oil for the drying process takes some time. For a processing time of 70 hours the moisture content of the test transformers was reduced from 2% to

1.9% at temperature of 50C to 75C. Apparently only surface moisture was affected. A more effective method is to remove the oil and heat the insulation under vacuum.

VII. Computer Jargon 101

There's a lot of new terminology out there for the distribution engineer to assimilate these days. This section outlines some of the terms and concepts we see with the emphasis these days on data and voice communications.

1. **Telecommunications** is defined as the exchange of information, usually over a significant distance and using electronic equipment for transmission.
2. The **PBX**, is a private business exchange. It is the most advanced customer-premises equipment telecommunications solution. A PBX acts like a mini-central office. Almost all are digital.
3. **Asynchronous Transmission** means each device must be set to transmit and receive data at a given speed, known as a data rate. This type of transmission is also known as start-stop transmission because it uses start and stop bits.
4. **Synchronous Transmission** normally involves large blocks of characters, and special sync characters which are used to adjust to the transmitters exact speed.
5. The **organizations** which have the most impact on data communications are: ANSI, IEEE, EIA, ECSA, NIST, ISO
6. **RS-232-C** is one of the most common interfaces for data communications in use today. It is an EIA standard defining exactly how ones and zeros will be transmitted.
7. **DDS** is AT&T's Dataphone Digital Services which provides digital circuits for data transmission speeds of 2400, 4800, 9600, 56 kbps and 64 kbps.
8. **T-1** carrier service transmits at 1.544 Mbps and carries approximately 24 channels.
9. **ISDN** is the Integrated Services Digital Network
10. For **Fiber Optic** cable, data rates can exceed a trillion bits per second.
11. **Satellite** bandwidth can be up to many Mbps.
12. **Baseband** is a single data signal which is transmitted directly on a wire.
13. **Broadband** transmits data using a carrier signal.
14. **Buffering** is holding data temporarily, usually until it has been properly sequenced, as in packet switching networks, or until another device is ready to receive it, as in front-end processors.
15. **Polling** is the method used by a host computer or front end processor to ask a terminal if it has data to send.,
16. **Selecting** is the method used by a host computer to ask a terminal if it is ready to receive data.
17. A **Front End Processor** can perform:
 - Error detection
 - Code conversion
 - Protocol conversion

- Data conversion
 - Parallel/Series conversion
 - Historical logging
 - Statistical logging
18. **Security Measures:**
- Secure transmission facility
 - Passwords
 - Historical and Statistical Logging
 - Closed user group
 - Firewalls
 - Encryption and decryption
 - Secret keys
19. **Communications architectures and protocols** enable devices to communicate in an orderly manner, defining precise rules and methods for communications and ensuring harmonious communications among them.
20. In **Packet Switching Networks**, the data is separated into packets or blocks, and sent through the packet switching network to the destination.
21. A **Local Area Network** is a privately owned data communications system that provides reliable, high speed, switched connections between devices in a single building, campus or complex.
22. **Client/Server** - rather than running all applications on a single mainframe, users can access programs on servers attached to a LAN when a common database or resource is important. Bridges are used to extend LAN's beyond its usual distance limitation.
23. **Bridges** are used to connect two or more networks that use similar data communications.
24. **Routers** interconnect LAN's and do not require all users to have unique addresses (as do bridges).
25. **Gateways** connect networks using different communications methods.

VIII. Decibels

Here's some interesting information on decibels:

Decibels	Power Change	Decibels	Power Change
1	1.25	10	10.0
2	1.58	11	12.6
3	2.0	12	15.8
4	2.5	13	20.0
5	3.15	14	25.1
6	4.0	15	31.6
7	5.0	20	100
8	6.3	30	1000
9	7.9	40	10000

1 db = lowest sound that can be heard
30 db – whisper
70 db = human voice
100 db = loud radio
120 db = ear discomfort

IX. Faults and Inrush Currents

The following are some observations of the author based on many years of monitoring. The following statistics are real and based on actual measurements:

- **Voltage unbalance** is generally less than 1%
- **Harmonics** at the substation are generally less than 1 or 2%
- 40% of faults occur in **adverse weather**
- **Average line-to-ground fault current** was 1530 amps.
- Faults generally lasted 10 cycles with 2 seconds the maximum
- Essentially there is no fault impedance (see HtoF #1)
- **Voltage rise** during a fault was about 4% at the substation and 35% on the feeder
- Average fuse $I^2 \cdot t$ was 227,000 amp² sec, with the highest being 800,000 amp² sec
- **What you calculate is what you get.**
- 79% of all faults involve only one phase
- Most faults occur with 5% of peak voltage so offset is minimal
- Average **DC offset** was 1.1 with a time constant of 2.81 milliseconds
- **Inrush**
 - Inrush average was 2500 amps. And max. was 5700 amps.
 - Peak offset was 5.3 per unit and average time constant was 3 cycles
- **Cold Load Pickup** looks like inrush.

X. Custom Power Devices

Custom Power Devices are devices rated above 600 volts that are used to increase power quality. Though not widely used, these devices are available to the industry to reduce the impact of distribution disturbances, primarily sags. A few of these devices are described as follows:

- **Distribution Static Compensator (DSTATCOM)** – The DSTATCOM is a power electronic device that responds in less than a cycle. It shields customers from voltage sags and surge problems cause by sudden load changes on the system.
- **Dynamic Voltage Restorer (DVR)** – The DVR system is a series-connected power electronic device that restores voltage quality delivered to a customer when the line-side voltage deviates. The device supplies the elements missing from the waveform in less than one cycle.

- **Medium-Voltage Sub-Cycle Transfer Switch (SSTS)** – This device provides power quality to customers that are served radially and have access to an alternative power source. Switching between the preferred and alternative source is done within One-sixteenth of a second.
- **Solid-State Breaker (SSB)** – This is a fast acting sub-cycle breaker which instantaneously operates to clear an electrical fault from the power system. In combination with other electronic devices, the SSB can prevent excessive fault currents from developing and improve PQ.
- **Static Var Compensator (SVC)** – This device uses capacitors, an inductor, and a set of solid-state switches to provide power factor correction or voltage regulation. Constant power factor and constant line voltage are possible using the device.

XI. Cost of Power Interruption

The cost of an interruption is probably one of the most difficult to assess. On the one hand, when the perception is that the utility will pay the costs from commercial and industrial customers are always high via survey data. On the other hand, when the cost of correction of the problem is determined to be the customer's responsibility, the costs are much lower. The following are some of these survey costs. Use with caution:

<u>Type of Industrial /Commercial</u>	<u>Cost per peak KW</u>
Electrical Products	\$7.60
Crude Petroleum	\$240.30
Machinery	\$6.70
Paper Products	\$6.60
Logging	\$1.80
Printing and Publishing	\$5.20
Primary Textiles	\$15.10
Transportation	\$37.40
Textile	\$15.10
Automotive	\$36.90
General Merchandize	\$26.20
Household Furniture	\$34.70
Personal Services	\$0.30
Entertainment	\$20.70

XII. Cost of Sectionalizing Equipment

The following are some approximate costs of equipment used for sectionalizing:

Fuse Cutout	\$1300
Gang Operated Switch	\$5500
Disconnect Switch	\$2500
OCR	\$9000
DA Load Break	\$33,000
DA Recloser	\$40,000

XIII. Maintenance of Equipment

Some of the diagnostic and assessment techniques used for utility equipment is as follows:

TRANSFORMERS	SWITCHGEAR	CABLE	GENERATORS
Overall dielectric – DGA, online VHF/UHF PD	Drive – contact position, constant velocity, vibrational analysis, trip-coil current	PD Techniques – 0.1 Hz off-line detection and localization, online VHF detection, single/double sided localization in point to point cables and branched networks	Stator/Rotor Windings – insulator resistance, conductor resistance, polarization index, loss angle, capacitance P”D measurement, high voltage tests, video endoscopy
Tap Changer – dynamic resistance, drive power	Secondary System – trip-coil current	Diel Spectroscopy – loss angle, capacitance	
Bushing – loss angle, capacitance	Overall Dielectric – online PD, vacuum leak testing		
Core – no load losses			
Paper - furfural analysis			

Transformer Lifetime from furfural analysis:

- Lifetime primarily determined by mechanical condition of paper insulation
- Degree of polymerization (DP) measure for mechanical strength
- DP decreases from about 1200 (new) to 250 (end of life)
- DP determined from correlation with product of furfural and CO-concentrations
- Decay curve from accelerated aging study
- Lifetime time prediction from (series) of DP values

IX. Major Events

In the area of reliability indices some utilities are allowed to exclude major events (storms, etc.). The concern in the industry is what constitutes a major event. There are many definitions. The two most popular are:

- 10% of the system is out of service for usually 24 hours
- Exclusion of events outside 3 sigma. This definition is based on Chebyshevs Inequality (you needed to know that right!). Anyway, outages a utility may have during the year have a probability distribution. This concept basically says that events not within 3 standard deviations of the mean can be excluded. For reference, approximately 56% of events are within 1 standard deviation, 75% are within 2 standard deviations and 89% are within 3 standard deviations. So this would mean approximately 10% could be excluded.

X. Line Charging Current

I'm asked about once a year how much capacitance a line has. Always have trouble finding an answer so I'm putting it here. Charging KVA (3 phase) can be approxiated by the formula: Charging KVA = $2.05 (kV)^2/Z$, where Z is the characteristic impedance of the line. Some approximations, which may be helpful, are as follows:

kV	Overhead (kVAR)	Underground (kVAR)
15	1	10
25	3	30
35	6	60
115	66	660
230	265	2,650
500	1,250	12,500

XI. Overcurrent Rules

1. **Hydraulically controlled recloser** are limit to about 10,000 amperes for the 560 amp coil and 6000 amperes for the 100 amp coil.
2. Many companies set ground minimum trip at maximum load level and phase trip at 2 times load level.
3. A **K factor** of 1 (now used in the standards) means the interrupting current is constant for any operating voltage. A recloser is rated on the maximum current it can interrupt. This current generally remains constant throughout the operating voltage range.
4. A **recloser** is capable of its full interrupting rating for a complete four-operation sequence. The sequence is determined by the standard. A breaker is subject to derating.
5. A **recloser** can handle any degree of asymmetrical current. A breaker is subject to an S factor de-rating.

6. A **sectionalizer** is a self-contained circuit-opening device that automatically isolates a faulted portion of a distribution line from the source only after the line has been de-energized by an upline primary protective device.
7. A **Power Fuse** is applied close to the substation (2.8 to 169kV and X/R between 15 and 25)
8. A **Distribution Fuse** is applied farther out on the system (5.2 to 38kV and X/R between 8 and 15).
9. The **fuse tube** (in cutout) determines the interrupting capability of the fuse. There is an auxiliary tube that usually comes with the fuse that aids in low current interruption.
10. Some **expulsion fuses** can handle 100% continuous and some 150%.
11. Type **“K”** is a fast fuse link with a speed ratio of melting time-current characteristics from 6 to 8.1 (speed is the ratio of the 0.1 minimum melt current to the 300 second minimum melt current. Some of the larger fuses use the 600 second point.
12. Type **“T”** is a slow fuse link with a speed ratio of melt time-current characteristics from 10 to 13.
13. After about 10 fuse link operations, the **fuse holder** should be replaced.
14. **Slant ratings** can be used on grounded wye, wye, or delta systems as long as the line-to-neutral voltage of the system is lower than the smaller number and the line-to-line voltage is lower than the higher number. A slant rated cutout can withstand the full line-to-line voltage whereas a cutout with a single voltage rating could not withstand the higher line-to-line voltage.
15. **Transformer fusing** – 25@0.01, 12@0.1, 3@10sec.
16. **Unsymmetrical Transformer Connections** (delta/wye):

<u>Fault Type</u>	<u>Multiplying Factor</u>
Three-phase	N
Phase-to-phase	.87 (N)
Phase-to-Ground	1.73 (N)

Where N is the ratio of $V_{\text{primary}}/V_{\text{secondary}}$
(Multiply the high side device current points by the appropriate factor)
17. **K Factor for Load Side Fuses**
 - 2 fast operations and dead time 1 to 2 seconds = 1.35
18. **K Factor for Source Side Fuses**
 - 2 fast-2 delayed and dead time of 2 seconds = 1.7
 - 2 fast-2 delayed and dead time of 10 seconds = 1.35
 - Sometimes these factor go as high as 3.5 so check
19. **Sequence Coordination** – Achievement of true “trip coordination” between an upline electronic recloser and a downline recloser, is made possible through a feature known as “sequence” coordination. Operation of sequence coordination requires that the upline electronic recloser be programmed with “fast curves” whose control response time is slower than the clearing time of the downline recloser fast operation, through the range of fault currents within the reach of the upline recloser: Assume a fault beyond the downline recloser that exceeds the minimum trip setting of both reclosers. The downline recloser trips and clears before the upline recloser has a chance to trip. However, the upline control does

see the fault and the subsequent cutoff of fault current. The sequence coordination feature then advances its control through its fast operation, such that both controls are at their second operation, even though only one of them has actually tripped. Should the fault persist, and a second fast trip occur, sequence coordination repeats the procedure. Sequence coordination is active only on the programmed fast operations of the upline recloser. In effect, sequence coordination maintains the downline recloser as the faster device.

20. Recloser Time Current Characteristics

- Some curves are average. Maximum is 10% higher.
- Response curves are the response of the sensing device and does not include arc extinction.
- Clearing time is measured from fault initiation to power arc extinction.
- The response time of the recloser is sometimes the only curve given. To obtain the interrupting time, you must add approximately 0.045 sec to the curve (check...they're different)
- Some curves show max. clearing time. On the new electronic reclosers, you usually get a control response curve and a clearing curve.
- $Z_{I-g} = (2Z_1 + Z_0)/3$

21. The **“75% Rule”** considers TCC tolerances, ambient temperature, pre-loading and pre-damage. Pre-damage only uses 90%.

22. A **back-up current limiting fuse** with a designation like “12K” means that the fuse will coordinate with a K link rated 12 amperes or less.

23. Capacitor Fusing:

- The 1.35 factor may result in nuisance fuse operations. Some utilities use 1.65
- Case rupture is not as big a problem as years ago due to all film designs.
- Tank rupture curves may be probable or definite in nature. Probable means there is a probability chance of not achieving coordination. Definite indicates there is effectively no chance of capacitor tank rupture with the proper 0% probability curve.
- T links are generally used up to about 25 amperes and K link above that to reduce nuisance fuse operations from lightning and in

24. **Line Impedance** – Typical values for line impedance (350kcm) on a per mile basis are as follows:

	$Z_{positive}$	Z_0
Cable UG	.31 + j0.265	1.18 + j0.35
Spacer	.3 + j0.41	1.25 + j2.87
Tree Wire	.3 + j0.41	1.25 + j2.87
Armless	.3 + j0.61	.98 + j2.5
Open	.29 + j0.66	.98 + j2.37

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EXPERIENCE

Mr. Burke joined ABB in 1997 as an Institute Fellow at ABB's Electric systems Technology Institute. In 1999 he accepted a position within ABB as Manager of Distribution Engineering Services and in 2000 as an Executive Consultant. He is recognized throughout the world as an expert in distribution protection, design, power quality and reliability.

Mr. Burke began his career in the utility business with the General Electric Company in 1965 training and taking courses in generation, transmission and distribution as part of GE's Advanced Utility Engineering Program. In 1969, he accepted a position as a field application engineer in Los Angeles responsible for transmission and distribution system analyses, as well as generation planning studies for General Electric's customer utilities in the Southwestern states. In 1971 he joined GE's Power Distribution Engineering Operation in New York where he was responsible for distribution substations, overcurrent and overvoltage protection, and railroad electrification for customers all over the world. During this period he was involved with the development of the MOV "riser pole" arrester, the Power Vac Switchgear, the static overcurrent relay and distribution substation automation.

In 1978 Mr. Burke accepted a position at Power Technologies Inc. (PTI) where he continued to be involved with virtually all distribution engineering issues. During this period he was responsible for the EPRI distribution fault study, the development of the first digital fault recorder, state-of-the-art grounding studies, and numerous lightning and power quality monitoring studies. In the area of railroad electrification he was co-author of the EPRI manual on "Railroad Electrification on Utility Systems" as well as project manager of system studies for the 25 to 60 Hz conversion of the Northeast Corridor. Until his departure in 1997, he was manager of distribution engineering.

He was the project manager for the first 50,000 volt electrified railroad, the industries first microprocessor based fault

recorder, the first riser pole arrester using metal oxide, the first five wire distribution system, and the first digital simulation of MOV's for distribution systems. He also managed numerous projects including the EPRI's distribution fault study, the successful use of MOV line protection for a 115kV line and many others in the areas of power quality, reliability, overcurrent protection, overvoltage protection, capacitor application, automation, planning, etc.

He has authored and co-authored over 100 technical papers, including two prize papers. He is the author of the book "**Power Distribution Engineering: Fundamentals & Applications**", now in its fifth printing. He is author of the last two revisions to the chapter on Distribution Engineering in the "**Standard Handbook for Electrical Engineering.**"

EDUCATION

BSEE - Univ. of Notre Dame
MSIA – Union College – Thesis:
"Reliability and Availability Analysis
of Direct Buried Distribution
Systems"
PSEC – GE (Schenectady)

PROFESSIONAL ACTIVITIES

IEEE

Chair: Dist. Neutral Grounding
Chair: Distribution Voltage Quality
Past Chair: Distribution Subcom.
Member – T&D Committee
Member – Surge Protective Device
Committee

ACHIEVEMENTS & HONORS

IEEE Awards

Fellow (1992)
Standards Medallion (1992)
2 Prize Papers
The 1996 Award for "*Excellence in
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Distinguished Lecturer in PQ

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1. "An Availability and Reliability Analysis of Direct Buried and Submersible Underground Distribution Systems," *IEEE Transactions* Conference paper, Underground Conference Detroit, Mich., June 1970 (co-author: R. H. Mann)
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24. "Compensation Techniques to Increase Electrified Railroad Performance," *IEEE Transactions*, presented at the IEEE/ASME Joint Conference, Norfolk, VA, April, 1986.
25. "Factors Affecting the Quality of Utility Power, APPA Conference, May 28, 1986, Colorado Springs, CO.
26. "Fault Impedance Considerations for System Protection", presented at the T&D Conference, Anaheim, CA, September 1986
27. "Cost/Benefit Analysis of Distribution Automation," presented at the American Power Conference, Chicago, IL, April 1987
28. "The Effect of Higher Distribution Voltages on System Reliability," Panel Session, IEEE Summer Power Meeting, San Francisco, CA, 1987.
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30. "Utility Operation and Its Effect on Power Quality," IEEE Winter Power Meeting Panel Session, February 1988.
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