POWER QUALITY
ENEE 435

Lecture : 3 **Year : IV**
Tutorial : 2 **Part : I**
Practical : 1

Course Objectives:
This course introduces the fundamentals of power quality, covering transients, voltage sags and swells, and harmonics, with their causes, effects and standards. It also presents compensation techniques and the instruments and methods used to monitor and mitigate power quality problems.

1 Introduction to Power Quality (10 hours)

1.1 Concept of power quality
1.2 Characterization of Electric Power Quality: Transients, short duration and long duration voltage variations, voltage imbalance, waveform distortion, voltage fluctuations, power frequency variation, leakage current in earthing systems
1.3 International standards and power acceptability curves: IEEE and IEC, CBEMA and ITIC curves
1.4 Power Quality Problems: Overview on sources of power quality problems (utility and end user side), Poor load power factor, non-linear and unbalanced loads, DC offset in loads, grounding and wiring problems, nuisance tripping
1.5 Transient overvoltages: Switching events and lightning phenomena
1.6 Capacitor switching overvoltages and transients: LC resonance in capacitor switching, evaluating overvoltages during the switching process, Magnification of voltage
1.7 Surge Propagation: Travelling waves, Reflection and Transmission of travelling waves, travelling waves at inductor and capacitor termination, lattice diagrams, lightning phenomena, modelling lightning surges, volt-time curves
1.8 Protection against Transient Overvoltages: Review of surge diverters, non-linear resistor in arresters, metal oxide arresters
1.9 General approaches to power quality solutions

2 Voltage Sag, Swells and Interruption in Power System (9 hours)

2.1 Voltage sag and Interruption: Definitions, causes (faults, motor starting, transformer energization), short interruptions
2.2 Voltage sag calculation: Voltage sag analysis and calculation for various fault conditions

2.3 Estimating voltage sag performance: Area of Vulnerability, Equipment Sensitivity to Voltage Sags
2.4 Estimation of the sag severity
2.5 Mitigation of voltage sag: Motor-generator sets, electronic tap changer, Ferro resonant transformers, Series voltage controller (DVR), Static VAR compensators (SVC), Static transfer switches and fast transfer switches
2.6 Causes and Mitigation of voltage swells
2.7 Economic impact of voltage sags

3 Power System Harmonics (9 hours)

3.1 Harmonic distortion: Fourier series, voltage and current distortion, power in non-sinusoidal conditions
3.2 Harmonic indices
3.3 Harmonic sources from commercial and industrial loads, harmonic sequences
3.4 Effects of harmonics on various equipment: Rotating machines, Transmission lines, Transformer and Capacitor banks
3.5 Harmonic distortion evaluation: Harmonic resonance (series and parallel), harmonic propagation
3.6 Harmonic elimination: Solutions for triplens, Passive and active filters
3.7 IEEE and IEC standards

4 Compensation techniques (9 hours)

4.1 Principle of load compensation: Power Factor and its Correction, Voltage Regulation, Approximate Expression for the Voltage Regulator
4.2 Practical Aspects of Compensator Used as Voltage Regulator
4.3 Voltage unbalance and phase balancing: Causes, effects, unbalance factor; phase balancing and power factor correction of unbalanced loads
4.4 Dynamic voltage regulator (DVR)- structure and working principle
4.5 Shunt Compensators: D-STATCOM and Shunt Active Filter: structure and working principle
4.6 Unified power quality conditioner-operating principle, configuration

5 Power Quality Monitoring (8 hours)

5.1 Monitoring considerations: Purposes of power quality surveys and monitoring, monitoring objectives and locations
5.2 Power quality monitoring standards
5.3 Power quality measurement equipment
5.4 Disturbance Analyzers
5.5 Spectrum analyzers and Harmonic analyzers
5.6 Voltage fluctuations and flicker: Sources, effects, flicker meters
5.7 Data Analysis for power quality monitoring: Application of expert systems

Tutorial **(30 hours)**

1. Classification of Power Quality Disturbances using waveform examples, and the application of power acceptability curves (CBEMA and ITIC) to assess whether given events are tolerated.
2. Numerical exercises on capacitor switching transients and voltage magnification
3. Travelling wave problems: reflection and transmission coefficients, lattice diagrams, and selection of surge arrester ratings
4. Calculations of voltage sag problems and their mitigations
5. Numerical exercises to understand the concept of total harmonic distortion and the contributions of individual harmonic components on the THD.
6. Evaluation of harmonic resonance (series and parallel) in a system with a capacitor bank, Procedure for harmonic filter design
7. Application of compensation techniques DSTATCOM, DVR and UPQC
8. Power quality monitoring data analysis (event detection, sag and harmonic statistics, flicker assessment)

Practical **(15 hours)**

1. Measurement and Analysis of Power Quality Parameters
2. Investigation of Harmonic Distortion Using a Nonlinear Load
3. Power-Factor Correction Using Capacitor Banks
4. Investigation of Voltage Sag and Swell
5. Power Quality Monitoring and Disturbance Diagnosis

Final Exam

The questions will cover all the chapters in the syllabus. The evaluation scheme will be as indicated in the table below:

Chapter	Hours	Mark distribution*
1	9	14
2	9	12
3	9	14
4	9	12
5	9	8
Total	**45**	**60**

* There may be minor deviation in marks distribution.

References

1. Arrillaga, J., Watson, N. R., & Chen, S. (2000). Power system quality assessment. Wiley.
2. Bollen, M. H. J. (2000). Understanding power quality problems: Voltage sags and interruptions. IEEE Press.
3. Dugan, R. C., McGranaghan, M. F., Santoso, S., & Beaty, H. W. (2003). Electrical power systems quality (2nd ed.). McGraw-Hill.

4. Greenwood, A. (1991). Electrical transients in power systems (Latest ed.). John Wiley & Sons.
5. Heydt, G. T. (1994). Electric power quality (Latest ed.). Stars in a Circle Publications.
6. Kennedy, B. W. (2000). Power quality primer. McGraw-Hill.
7. Singh, B., Chandra, A., & Al-Haddad, K. (2015). Power quality problems and mitigation techniques. Wiley.

ADVANCED POWER SYSTEM PROTECTION
ENEE 436

Lecture : 3 **Year : IV**
Tutorial : 2 **Part : I**
Practical : 1

Course Objectives:
Students will be able to understand digital/computer protective relaying principles and algorithms, apply protection schemes to major power system components, and explore modern technologies such as WAMS, PMUs, adaptive protection, and digital relays.

1 Introduction to digital/computer relaying (6 hours)

1.1 Brief of power system protection: electromagnetic, static, and digital/computer relays
1.2 Relay operating principles of digital/computer relaying
1.3 Expected benefits of computer relaying
1.4 Computer relay architecture, substation computer hierarchy
1.5 Analogue signal conditioning, A/D conversion
1.6 Aliasing filters, Sampling, low pass filters

2 Mathematical basis for protective relaying algorithms (10 hours)

2.1 Review of Fourier transforms and discrete Fourier transform (DFT)
2.2 Full cycle DFT, half cycle DFT, cosine filter
2.3 Least square technique
2.4 Estimation of phasor and harmonic component
2.5 Frequency Response of Phasor Estimation techniques and decaying DC

3 Computer relaying for transmission lines (10 hours)

3.1 Introduction, stepped distance protection, 3 zone protection
3.2 R-X diagram, MHO relay characteristics
3.3 Measurement of distance to different types of faults; phase to phase faults, ground faults, fault resistance
3.4 Distance relay algorithm: radial, parallel, and multi terminal lines
3.5 Directional relay, forward and reverse faults
3.6 Use of differential equation algorithm and relaying program
3.7 Pilot protection: power line carrier, microwave, fiber optics, communication cable

4 Computer relaying for protection of transformers, rotating machines (6 hours)

4.1 Power transformer protection algorithms,
4.2 Generator and motor protection algorithms,
4.3 Digital bus protection

5 Basic concepts: WAMS based Protection (8 hours)

5.1 WAMS basics: phasors, GPS, PMU, PDC, WAMS architecture
5.2 Adaptive relaying: Introduction, examples of adaptive relaying for transmission line, transformer, reclosing
5.3 WAMS based out of step relaying
5.4 Supervision of back up zones, intelligent load shedding, intelligent islanding, load shedding and restoration

6 Hardware organization in integrated systems (8 hours)

6.1 Nature of hardware issues
6.2 Computer relaying and substation environment
6.3 Countermeasures against EMI
6.4 Supplementary equipment: (Power supply, auxiliary relays, test switches, interface panel)
6.5 Redundancy and back up
6.6 Servicing, training and maintenance

Tutorial (30 hours)

1. Understanding digital/computer-based relays architecture and operating principles
2. Understand the sampling theorem, A/D conversion, antialiasing and low pass filters
3. Numerical related to DFT, Full cycle DFT, half cycle DFT, cosine filter, least square techniques
4. Numerical related to estimation of phasors, harmonic and dc components
5. Finding accurate distance in radial feeder protection for different types of faults using relaying algorithm
6. Numerical related to directional relays using relaying algorithm and designing directional over current relaying schemes in radial, parallel, three terminals in digital relaying platform
7. Designing directional over current relaying schemes parallel and three terminals in digital relaying platform
8. Understanding pilot protection system
9. Understanding PMU and WAMS architecture and applications in networks in power systems
10. Understanding computer-based relays hardware

Practical (15 hours)

The computer-based simulation laboratory exercises and a mini project are designed to provide students with experience in digital and computer-based power system protection using standard educational software

1. To simulate the conversion of analog voltage and current signals into digital quantities and estimate their fundamental phasors using digital signal-processing techniques.
2. To simulate and test a three-zone digital distance protection scheme for a two-bus system.
3. To develop a protection system for a selected section of the real Integrated Nepal Power System (INPS), comprising transmission lines and/or distribution feeders with a minimum of 12 buses, using appropriate network and system data. The project shall include system modeling, fault analysis, selection and application of suitable numerical relaying algorithms, relay setting and coordination, and performance evaluation of the proposed protection schemes under different operating and fault conditions

Final Exam

The questions will cover all the chapters in the syllabus. The evaluation scheme will be as indicated in the table below:

Chapter	Hours	Mark distribution*
1	6	8
2	10	14
3	10	14
4	6	8
5	8	10
6	5	6
Total	**45**	**60**

* There may be minor deviation in marks distribution.

References

1. Horowitz, S. H., Phadke, A. G., & Henville, C. F. (2022). Power system relaying (Latest ed.). Wiley.
2. Anderson, P. M., Henville, C., Rifaat, R., Johnson, B., & Meliopoulos, S. (2022). Power system protection (2nd ed.). Wiley-IEEE Press.
3. Phadke, A. G., & Thorp, J. S. (2017). Synchronized phasor measurements and their applications (Latest ed.). Springer.
4. Phadke, A. G., & Thorp, J. S. (2009). Computer relaying for power systems (Latest ed.). John Wiley & Sons.
5. Power System Relaying Committee, & Sachdev, M. S. (1992). Understanding microprocessor-based technology applied to relaying. IEEE Power Engineering Society.
6. Rao, T. S. M. (2005). Digital/numerical relays. Tata McGraw-Hill.