Write a comprehensive, detailed summary with beautiful formatting.with all formulas

Certainly! Below is a comprehensive and detailed summary of the key topics covered in the document, organized by chapters and highlighting important concepts and formulas.

Power Systems Research and Operation: Selected Problems

---

1. Decentralized Market Coupling with Power Systems Transmission Network Constraints

Overview:
This chapter develops theoretical and methodological foundations to assess the impact of transmission network constraints on electricity exchange during the integration of electricity markets, particularly focusing on the day-ahead market (DAM) segment. It discusses market coupling methods, including Flow-Based Market Coupling (FB MC) and Decentralized Market Coupling (DMC), their limitations, and proposes a novel approach to improve DMC for multiple coupled electricity markets.

Key Concepts:

- **Flow-Based Market Coupling (FB MC):**
  - Objective function maximizes social welfare:

$$\max \sum_{i \in \text{Area}} \left[\int_0^{q_i^d} p_i(q)dq - \int_0^{q_i^s} c_i(q)dq \right]$$

  - Subject to:

$$\mathbf{R} \cdot (\mathbf{q}^s - \mathbf{q}^d) \leq \mathbf{q}_{\max}$$

    where

$$q_i^d$$

    and

$$q_i^s$$

    are demand and supply in area

$$i$$

,

$$p_i(q)$$

and

$$c_i(q)$$

are price functions,

$$\mathbf{R}$$

is the Power Transfer Distribution Factor (PTDF) matrix, and

$$\mathbf{q}_{\max}$$

are line capacity limits.

- **Decentralized Market Coupling (DMC):**
  Uses Net Export Curves (NEC), defined as:

  $$\text{NEC}(C) = P_s(C) - P_d(C)$$

  where

  $$P_s(C)$$

  and

  $$P_d(C)$$

  are supply and demand as functions of price

  $$C$$

  .

- **New Method for DMC:**
  Minimizes the difference in marginal prices between coupled zones, considering network constraints for arbitrary number of coupled markets with arbitrary electrical coupling structures. The exchange volume between two zones

  $$A$$

  and

  $$B$$

  is:

  $$V_{A\to B}^{\text{Coup}} = \begin{cases} -\min\left(\max(\text{NEC}_B(C_B)), \min(\text{NEC}_A(C_A)), V_{B\to A}^{\max}\right), & C_A \geq C_B \\ \min\left(\min(\text{NEC}_B(C_B)), \max(\text{NEC}_A(C_A)), V_{A\to B}^{\max}\right), & C_A \leq C_B \\ 0, & C_A = C_B \end{cases}$$

Application:

Applied to assess integration feasibility of the Ukrainian Power System's Burshtyn TPP Energy Island (BEI) to European electricity markets. Findings show significant challenges due to supply-demand incompatibilities and the need for ancillary service markets to ensure operational security [[10]-[25]].

---

2. Improving the Reliability and Power Quality in Distribution Networks with Dispersed Generation

Overview:
The chapter addresses challenges in distribution networks (DN) with dispersed generation (DG) and energy storage, which cause fluctuating load flows. It proposes methods for optimal network reconfiguration, reliability improvement, and power loss minimization using remote-controlled switching devices and power electronics-based Soft Open Points (SOP).

Key Points:

- **Reliability Indicators:**
  Integral indices such as SAIFI, SAIDI, EENS, ASIDI, and ASIFI are used to quantify power supply reliability.
- **Expected Energy Not Served (EENS):**
  Calculated as:
  $$\text{EENS} = \sum_{m=1}^{M} z_{0m} K_m r_b P$$
  where
  $$z_{0m}$$
  is the failure rate,
  $$K_m$$
  number of elements,
  $$r_b$$
  average restoration time, and
  $$P$$
  load disconnected.
- **Optimal Sectioning Algorithm:**
  Iteratively places switching devices to minimize reliability indices and cost.
- **Dynamic Reconfiguration:**
  Using remote-controlled switching devices, the network topology can adapt to cyclic load and DG fluctuations. Rational switching is based on:
  - Daily heterogeneity of power flows;
  - Forecasting of loads and DG outputs;
  - Switching resource constraints.
- **Soft Open Points (SOP):**
  Power electronics devices (e.g., Voltage Source Converters - VSC) installed in DN allow controlled active/reactive power flow between network sections, combining open and closed network advantages.

- **SOP Control Objective:**
  Minimize active power losses:

$$P_{\text{loss}} = \sum_k \left(\frac{I_k}{I_{k,\text{nom}}} \right)^2$$

  or balance load flow close to ideal loop mode.

Sensor Placement and Reliability Improvement:

- Switching devices are placed considering their limited number of operations;
- DG integration requires coordinated sectioning for reliability normalization;
- The approach reduces energy losses and improves voltage profiles [[31]-[53]].

---

3. Some Features of Electromechanical Oscillations Modes Identification in Power Systems

Overview:
This chapter examines real-time identification of low-frequency oscillations (LFO) in power systems using signal processing methods applied to PMU data. It proposes an ensemble of signal analysis methods with a procedure to generalize results for reliable LFO mode parameter estimation.

Key Points:

- **LFO Classification by Frequency:**

Mode Type	Frequency Range (Hz)
Torsional	10 – 46
Intra-plant	2 – 3
Local plant	1 – 3
Intra-area	0.3 – 1
Inter-area	< 0.3

- **Signal Analysis Methods Tested:**
  FFT, Periodogram, Welch, Thomson multitaper, AR model methods (Yule-Walker, Burg), parametric exponential models (MUSIC, HTLS, MP, Prony), Wavelet Transform (Morlet), Stockwell Transform, Hilbert-Huang Transform (HHT) and its modifications.

- **Test Signals:**
  Synthetic signals with known modes are used to evaluate method accuracy and robustness.
- **Identification Procedure:**
  Modes with close frequencies are grouped; damping is classified via amplitude trends over observation windows.
- **Ensemble Approach:**
  Uses main methods (HTLS, MP, Prony) plus additional (MHHT-2). The modes identified by multiple methods are considered reliable.
- **Application to Real Data:**
  PMU measurements from Ukraine's power system validate the approach, identifying inter-area oscillations with varying frequencies and damping [[54]-[75]].

---

4. Hybrid Diagnostics Systems for Power Generators Faults

Overview:
The chapter presents design principles of hybrid diagnostic systems for power generators, focusing on capacitive shaft run-out sensors and their operation under electromagnetic and thermal influences. It emphasizes the importance of real-time monitoring for reliability and maintenance optimization.

Key Components:

- **System Architecture:**
  Uses fiber optic and electro-optical components to mitigate electromagnetic interference and temperature effects.
- **Capacitive Shaft Run-Out Sensor:**
  - Principle: Change in capacitance

    $$C$$

    due to variation in air gap

    $$d$$

    between sensor electrodes and shaft surface.

    $$C = \frac{\varepsilon_0 \varepsilon_r \pi r^2}{d}$$

    where

    $$\varepsilon_0$$

vacuum permittivity,

$$\varepsilon_r$$

relative permittivity, and

$$r$$

electrode radius.

- **Sensor Placement:**
  Multiple sensors placed orthogonally near shaft bearings to measure radial beating.
- **Environmental Influences:**
  - Temperature range: −30°C to +80°C tested with minimal impact on sensor characteristics.
  - Electromagnetic fields up to 0.68 T evaluated to ensure measurement accuracy.
- **Technological Factors:**
  Manufacturing imperfections like inter-electrode gap, electrode thickness, and dielectric substrate thickness affect sensor response.
- **Simulation and Experimental Results:**
  Detailed modeling guides optimal sensor design to maximize sensitivity and reliability [[78]-[105]].

---

5. Operating Modes Optimization of Bulk Electrical Power Networks

Overview:
This chapter discusses optimization of extra high voltage (EHV) transmission lines focusing on voltage and reactive power control, considering corona discharge losses and the use of controlled shunt reactors (CSR) and STATCOM devices.

Key Formulas:

- **Equivalent Longitudinal Admittance:**

  $$B_{\text{eq}} = \sin 2\lambda + b_P^* \sin^2 \lambda$$

  where

  $$b_P^* = 2 \tan \frac{\lambda}{2}$$

  is the relative conductance of the compensation device.

- **Active Power Losses Without Compensation:**

$$P_{\text{loss}} = \text{complex function of } R, X, G, B, U, P, Q$$

(detailed in Eq. 17 and 18)

- **Optimization Condition:**

$$\frac{\partial P_{\text{loss}}}{\partial U} = 0, \quad \frac{\partial P_{\text{loss}}}{\partial B_{\text{reac}}} = 0$$

Findings:

- CSR and STATCOM reduce active power losses significantly compared to uncontrolled shunt reactors.
- Operational optimization includes choosing optimal locations and capacities for reactive power compensation to minimize losses.
- The presence of corona discharge losses requires probabilistic models to accurately estimate losses under varying weather conditions.

Network-Level Optimization:

- Total active power loss in the network:

$$P_{\text{total}} = \sum_{i,j} P_{ij}$$

- Optimization of power flow distribution in heterogeneous closed networks to minimize losses.
- Sensitivity analysis and iterative methods (Newton-Raphson and Jacobian matrix) applied to determine optimal reactive power compensation points [[106]-[125]].

---

6. Short Term Renewable Energy Forecasting with Deep Learning Neural Networks

Overview:
Addressing the challenge of forecasting renewable energy sources (RES) generation, this chapter proposes a novel deep learning architecture for short-term forecasting of aggregated RES generation, improving forecasting accuracy and reducing imbalances in the power system.

Key Points:

- **Challenges:**
  RES generation is stochastic and variable, leading to forecasting errors and increased balancing costs.

- **Forecasting Approaches:**
  - Physical models using meteorological data and Numerical Weather Prediction (NWP).
  - Statistical and machine learning models, including ARIMA, Kalman filter, Support Vector Machines (SVM), and Artificial Neural Networks (ANN).
  - Hybrid models combining physical and statistical methods.
- **Deep Learning Architecture:**
  - Uses autoencoding units with shortcut connections (eResNet architecture).
  - Input vector length: 168 hours (previous values).
  - Output: 24-hour ahead forecasts including probabilistic quantiles (10th, 50th, 90th percentiles).
- **Neural Network Formulas:**

  Autoencoding unit output:

  $$x_{AE} = \mathrm{selu}(\mathrm{selu}(xW_1 + b_1)W_2 + b_2) + x$$

  where selu is the scaled exponential linear unit activation.

  Loss function combining mean squared error and quantile error:

  $$L = \mathrm{MSE} + QE_{10} + QE_{90}$$

- **Training:**
  Uses mini-batch gradient descent with Adam optimizer and cyclic batch size to avoid local minima.
- **Results:**
  The proposed model reduces average forecast error from 4.78% to 4.46%, and maximum error from 21.18% to 12.81%. Combining multiple models (ensembles) further improves accuracy [[127]-[145]].

---

7. Grids Transfer Capacity: Calculation Methodology and Features

Overview:
This chapter describes methodologies and challenges in calculating Total Transfer Capacity (TTC) of power system interfaces, focusing on operational stability, voltage stability, and contingency analysis, with application to the Ukrainian power system.

Key Concepts:

- **TTC Calculation:**
  TTC is limited by:
  - Aperiodic static stability (angle stability);
  - Voltage stability;
  - Thermal limits of equipment.
- **Static Stability Analysis:**
  Uses linearized system models:

  $$\Delta \dot{x} = A\Delta x + B\Delta u$$

  Stability requires eigenvalues

  $$\lambda_i$$

  of

  $$A$$

  to have negative real parts.
- **Margin Regimes:**
  Identified by:
  - Angle difference

    $$\delta < 90^\circ$$

    ;
  - PV curve inflection points;
  - Voltage limits;
  - Equipment loading limits;
  - Convergence of Newton-Raphson load flow iterations.
- **Voltage Stability Indicators:**
  - Reactive power reserves;
  - Voltage deviation;
  - Reactive power losses ratio;
  - Voltage sensitivity to reactive power fluctuations;
  - Jacobian determinant sign.
- **TTC Calculation Procedure:**
  - Define weighting trajectories for load/generation increase;
  - Apply operational and contingency margins:

    $$\mathrm{TTC}_i = \min\{\text{margins for normal conditions, contingencies...}\}$$
- **Sensitivity to Generator PQ-Characteristics:**
  Considering detailed PQ limits improves TTC accuracy.

- **Automated TTC Calculation Tool:**
  Developed in DIgSILENT PowerFactory, automates interface selection, trajectory building, contingency consideration, and margin calculations [[149]-[166]].

---

8. Frequency Stability of Bulk Isolated Power System with High Renewable and Nuclear Generation

Overview:
This chapter discusses frequency stability challenges in power systems with high shares of renewables and nuclear generation, including frequency characteristics identification, local frequency control, under-frequency load shedding (UFLS), and special protection automatics (SPA).

Key Points:

- **Frequency Characteristics Identification:**
  Based on SCADA-EMS data, stiffness coefficients

  $$K_f$$

  are defined as:

  $$K_f = \frac{\Delta P_g}{\Delta f}$$

  where

  $$\Delta P_g$$

  is generation change,

  $$\Delta f$$

  frequency change.

- **Local Active Power Controller (LAPC):**
  Designed to mitigate renewables impact on tie-line power flows. Control error:

  $$CE = (P_{\text{net}} - P_{\text{net.ref}}) + K_f(f - f_{\text{ref}}) + \Delta P^{ref}_{LAPC}$$

  with control signal:

  $$\Delta P^{ref} = K_P^{LC} CE + K_I^{LC} \int CE dt$$

- **Under-Frequency Load Shedding (UFLS):**
  Multi-stage relays with different frequency thresholds and response times reduce load to prevent system collapse.

- **Special Protection Automatics (SPA):**
  Protect nuclear plants by reducing or disconnecting generation based on frequency thresholds.
- **Simulation Results:**
  Demonstrate effective frequency regulation and load shedding to maintain system stability after disturbances [[167]-[180]].

References:

The document contains extensive references for each chapter, drawing from IEEE standards, EU regulations, Ukrainian energy system data, and international research in power system stability, control, and forecasting.

Summary

This monograph comprehensively addresses contemporary challenges and solutions in power systems operation and research, with a focus on:

- Market integration and congestion management via decentralized market coupling;
- Reliability and power quality improvements in distribution networks with dispersed generation;
- Real-time identification of electromechanical oscillations using advanced signal processing;
- Hybrid diagnostic systems for generator faults employing capacitive sensors;
- Optimization of extra high voltage transmission line operating modes including corona discharge considerations;
- Short-term forecasting of renewable energy generation using deep learning neural networks;
- Methodologies for calculating grid transfer capacity with stability and contingency margins;
- Frequency stability control in systems with high penetration of renewables and nuclear power.

The document integrates theoretical models, practical algorithms, and case studies primarily focused on Ukrainian power systems with comparisons to European practices, emphasizing the necessity for advanced control methods, diagnostics, and forecasting to ensure reliable, efficient, and stable power system operation.

If you need further details on any specific topic or formulas, feel free to ask!