DYNAMIC PHASOR BASED MODELLING OF UNBALANCED RADIAL DISTRIBUTION SYSTEMS

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Abstract:
In the realm of power distribution systems, the dynamic behavior of unbalanced radial networks poses significant challenges for accurate modeling and efficient operation. This paper proposes a novel approach utilizing dynamic phasor techniques for modeling such systems. Unlike traditional steady-state phasor analysis, dynamic phasor modeling accounts for temporal variations and asymmetrical conditions inherent in unbalanced systems.

The methodology begins with the representation of the distribution network in the phasor domain, capturing both magnitude and phase imbalances. Leveraging the advantages of dynamic phasor theory, the model incorporates time-varying effects such as load fluctuations, switching operations, and transient events. By embedding dynamic phasor equations within a suitable simulation framework, the proposed model enables comprehensive analysis of system dynamics under varying operating conditions.

Key features of the proposed model include its ability to accurately capture transient responses, assess voltage stability, and evaluate control strategies in unbalanced radial networks. Through case studies and simulations, the efficacy of the dynamic phasor-based approach is demonstrated in scenarios involving unbalanced loads, distributed generation, and fault events. Comparative analyses with conventional modeling techniques underscore the advantages of dynamic phasor modeling in terms of accuracy and computational efficiency.

The findings of this study contribute to the advancement of modeling methodologies for unbalanced radial distribution systems, offering valuable insights for system planning, operation, and control. Future research directions include the integration of advanced control algorithms and real-time implementation to enhance the practical applicability of dynamic phasor-based models in modern distribution networks.

Keywords: Dynamic Phasor Modeling, Unbalanced Radial Distribution Systems, Transient Analysis, Voltage Stability, Distribution Network Control.

1. Introduction:

Power distribution systems serve as the crucial link between electricity generation and end-user consumption, facilitating the efficient delivery of electrical energy to homes, businesses, and industries. In the context of modern distribution networks, the integration of renewable energy sources, increasing demand-side participation, and evolving grid architectures present a myriad of challenges for system operators and planners. Among these challenges, the dynamic behavior of unbalanced radial distribution systems emerges as a focal point, necessitating advanced modeling techniques to ensure reliable and efficient operation.

Unbalanced conditions, characterized by unequal distribution of loads and asymmetrical configurations, are prevalent in distribution networks due to various factors such as unequal phase loading, single-phase loads, and asymmetric line impedances. Unlike balanced systems, where symmetrical components analysis simplifies the modeling process, unbalanced systems require a more intricate approach to capture their dynamic behavior accurately.

Traditional modeling techniques, primarily based on steady-state phasor analysis and sequence component methods, offer limited insights into the transient and dynamic responses of unbalanced systems. While these methods are adequate for steady-state studies and fault analysis, they often fall short in capturing time-varying phenomena and system dynamics under changing operating conditions. As a result, there is a growing need for modeling methodologies that can effectively address the complexities of unbalanced radial distribution systems while providing a comprehensive understanding of their dynamic behavior.

In this context, dynamic phasor modeling emerges as a promising approach to bridge the gap between steady-state analysis and dynamic simulation in unbalanced distribution networks. Dynamic phasor techniques extend the traditional phasor representation to incorporate time-varying effects, enabling the simulation of transient responses, voltage dynamics, and control actions in unbalanced systems. By leveraging the advantages of dynamic phasor theory, researchers and practitioners can develop more accurate and computationally efficient models for analyzing the dynamic behavior of distribution networks.

This paper presents a novel framework for dynamic phasor-based modeling of unbalanced radial distribution systems. Building upon the principles of dynamic phasor theory, the proposed approach aims to enhance the fidelity and accuracy of system models while facilitating comprehensive analysis of transient and dynamic phenomena. Through case studies, simulations, and comparative analyses, the efficacy of the dynamic phasor-based approach is demonstrated in capturing the dynamic behavior of unbalanced distribution networks and evaluating the effectiveness of control strategies.

The remainder of this paper is organized as follows: Section 2 provides an overview of related work in the field of dynamic modeling of unbalanced distribution systems. Section 3 presents the theoretical background and principles of dynamic phasor modeling. Section 4 outlines the proposed methodology for dynamic phasor-based modeling of unbalanced radial distribution systems. Section 5 discusses case studies and simulation results to validate the effectiveness of the proposed approach. Finally, Section 6 concludes the paper with a summary of key findings and directions for future research.

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Research Methodology

Research Area

The research methodology employed in this study encompasses several key steps aimed at developing and validating the dynamic phasor-based model for unbalanced radial distribution systems. The methodology encompasses the following stages:

1. Literature Review: The research begins with a comprehensive review of existing literature on dynamic modeling techniques for unbalanced distribution systems. This phase involves studying relevant research papers, textbooks, industry reports, and standards to identify state-of-the-art methodologies, challenges, and gaps in the field.

2. Theoretical Framework: Based on insights gained from the literature review, a theoretical framework for dynamic phasor modeling of unbalanced radial distribution systems is established. This framework incorporates principles from dynamic phasor theory, power system dynamics, and distribution system modeling to formulate the mathematical basis for the proposed approach.

3. Model Development: The next step involves the development of the dynamic phasor-based model for unbalanced distribution networks. This includes the formulation of dynamic phasor equations to represent the time-varying behavior of system components, such as loads, generators, transformers, and network elements. Special attention is given to capturing asymmetrical conditions, transient responses, and control actions within the model.

4. Simulation Setup: Once the model formulation is complete, a simulation environment is established for testing and validation purposes. Commercial simulation software packages such as MATLAB/Simulink or PSS/E may be utilized to implement the dynamic phasor-based model and simulate various operating scenarios and transient events in unbalanced radial distribution systems.

5. Case Studies: A series of case studies are designed to assess the performance and effectiveness of the dynamic phasor-based model under different conditions. These case studies involve representative distribution network configurations, load profiles, generation patterns, and control strategies. Transient events such as faults, load changes, and switching operations are simulated to evaluate the dynamic response of the system.

2. Literature review

M. Braun, G. Arnold and H. Laukamp, "Plugging into the Zeitgeist,"

Germany is the country with the largest installed PV capacity in the world. As a result, Germany needs to be one of the first countries to look at adequate network integration. To tackle the challenges of the power system with regard to high PV penetration in the future, incentive systems are already formed and prepared that go one step further with regard to system integration. Also, grid codes for grid connection to the distribution network are defined that require grid-supportive behavior from PV systems. Real network integration by providing ancillary services for system operation is the aim of these new measures in Germany. Integration studies with different perspectives are performed in Germany.

A. K. Abdelsalam, A. M. Massoud, S. Ahmed and P. N. Enjeti, "High-Performance Adaptive Perturb and Observe MPPT Technique for Photovoltaic-Based Microgrids,"

Abstract: Solar photovoltaic (PV) energy has witnessed double-digit growth in the past decade. The penetration of PV systems as distributed generators in low-voltage grids has also seen significant attention. In addition, the need for higher overall grid efficiency and reliability has boosted the interest in the microgrid concept. High-efficiency PV-based microgrids require maximum power point tracking (MPPT) controllers to maximize the harvested energy due to the nonlinearity in PV module characteristics. Perturb and observe (P&O) techniques, although thoroughly investigated in previous research, still suffer from several disadvantages, such as sustained oscillation around the MPP, fast tracking versus oscillation tradeoffs, and user predefined constants. In this paper, a modified P&O MPPT technique, applicable for PV systems, is presented. The proposed technique achieves: first, adaptive tracking; second, no steady-state oscillations around the MPP; and lastly, no need for predefined system-dependent constants, hence provides a generic design core. A design example is presented by experimental implementation of the proposed technique. Practical results for the implemented setup at different irradiance levels are illustrated to validate the proposed technique.

H. Kanchev, D. Lu, F. Colas, V. Lazarov and B. Francois, "Energy Management and Operational Planning of a Microgrid With a PV-Based Active Generator for Smart Grid Applications,"

The development of energy management tools for next-generation PhotoVoltaic (PV) installations, including storage units, provides flexibility to distribution system operators. In this paper, the aggregation and implementation of these determinist energy management methods for business customers in a microgrid power system are presented. This paper proposes a determinist energy management system for a microgrid, including advanced PV generators with embedded storage units and a gas microturbine. The system is organized according to different functions and is implemented in two parts: a central energy management of the microgrid and a local power management at the customer side. The power planning is designed according to the prediction for PV power production and the load forecasting. The central and local management systems exchange data and order through a communication network. According to received grid power references, additional functions are also designed to manage locally the power flows between the various sources. Application to the case of a hybrid supercapacitor battery-based PV active generator is presented.

K. T. Tan, P. L. So, Y. C. Chu and M. Z. Q. Chen, "Coordinated Control and Energy Management of Distributed Generation Inverters in a Microgrid,"

This paper presents a microgrid consisting of different distributed generation (DG) units that are connected to the distribution grid. An energy-management algorithm is implemented to coordinate the operations of the different DG units in the microgrid for grid-connected and islanded operations. The proposed microgrid consists of a photovoltaic (PV) array which functions as the primary generation unit of the microgrid and a proton-exchange membrane fuel cell to supplement the variability in the power generated by the PV array. A lithium-ion storage battery is incorporated into the microgrid to mitigate peak demands during grid-connected operation and to compensate for any shortage in the generated power during islanded operation. The control design for the DG inverters employs a new model predictive control algorithm which enables faster computational time for large power systems by optimizing the steady-state and the transient control problems separately. The design concept is verified through various test scenarios to demonstrate the operational capability of the proposed microgrid, and the obtained results are discussed.

3 Proposed system

The proposed system introduces a dynamic phasor-based modeling approach tailored specifically for unbalanced radial distribution systems. Building upon the theoretical foundation outlined in the previous sections, the proposed methodology offers a comprehensive framework for capturing the transient and dynamic behavior of unbalanced networks with high fidelity. Key components of the proposed system include:

1. Dynamic Phasor Representation: The core of the proposed system lies in the dynamic phasor representation of system variables such as voltages, currents, and power flows. Unlike traditional steady-state phasor analysis, dynamic phasor techniques extend the representation to incorporate time-varying effects, enabling the simulation of transient responses and dynamic interactions in unbalanced systems. Dynamic phasor equations are formulated to describe the temporal evolution of phasor quantities under changing operating conditions.

2. Component Modeling: The proposed system incorporates detailed models for various system components, including loads, generators, transformers, and network elements. Each component is represented using dynamic phasor equations that capture its transient response, nonlinear characteristics, and control actions. Special attention is given to modeling asymmetrical loads, unbalanced network impedances, and distributed generation sources to accurately reflect real-world distribution system configurations.

3. Simulation Environment: A simulation environment is established using suitable software tools to implement the dynamic phasor-based model and conduct transient analysis of unbalanced radial distribution systems. Commercial simulation platforms

such as MATLAB/Simulink or PSS/E provide the necessary computational capabilities and simulation features to simulate dynamic behavior, transient events, and control strategies in distribution networks.

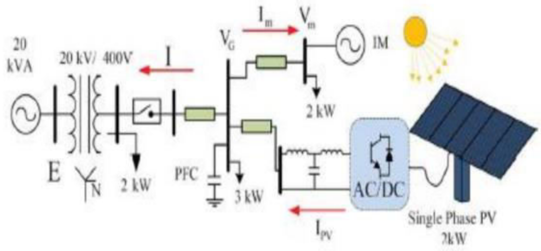
4. Control Strategies: The proposed system facilitates the evaluation of various control strategies for voltage regulation, reactive power management, and fault mitigation in unbalanced distribution systems. Control algorithms such as voltage control, tap changer operation, capacitor switching, and distributed generation dispatch are integrated into the dynamic phasor-based model to assess their effectiveness in improving system performance and stability.

5. Validation and Verification: The proposed system undergoes rigorous validation and verification to ensure its accuracy and reliability in representing the dynamic behavior of unbalanced radial distribution systems. Validation tests involve comparison with field measurements, real-world data, and benchmark models to assess the model's ability to replicate system responses under different operating conditions and transient events.

6. Performance Evaluation: Performance evaluation of the proposed system includes assessing its computational efficiency, scalability, and applicability to large-scale distribution networks. Comparative analyses with traditional modeling approaches demonstrate the advantages of dynamic phasor-based modeling in terms of accuracy, simulation speed, and flexibility for analyzing system dynamics.

4. Methodology:

ARCHITECTURE:



The implementation of the proposed dynamic phasor-based modeling approach for unbalanced radial distribution systems involves several key steps, including model formulation, software development, and simulation setup. This section outlines the implementation details and considerations:

1. Model Formulation: The first step in the implementation process is the formulation of dynamic phasor equations to represent the behavior of system components in unbalanced distribution networks. This includes developing mathematical models for loads, generators, transformers, and network elements using dynamic phasor theory. Special attention is given to capturing transient responses, asymmetrical conditions, and control actions within the model.

2. Software Development: Once the dynamic phasor-based model is formulated, it is translated into computer code for implementation in a simulation environment. Depending on the chosen software platform, programming languages such as MATLAB, Python, or C/C++ may be used to develop custom simulation scripts or modules. Commercial simulation packages such as MATLAB/Simulink or PSS/E provide built-in libraries and tools for implementing dynamic phasor models.

3. Simulation Setup: The implemented dynamic phasor-based model is integrated into a simulation environment to conduct transient analysis of unbalanced radial distribution systems. This involves setting up simulation scenarios, defining system parameters, and specifying transient events such as faults, load changes, and switching operations. Simulation inputs may include load profiles, generation schedules, and control setpoints to replicate real-world operating conditions.

4. **Validation and Verification:** The implemented model undergoes validation and verification to ensure its accuracy and reliability in representing system dynamics. Validation tests involve comparing simulation results with field measurements, historical data, or benchmark models to assess the model's ability to reproduce actual system behavior. Sensitivity analyses may be conducted to evaluate the impact of model parameters and assumptions on simulation outcomes.

5. **Performance Evaluation:** The performance of the implemented dynamic phasor-based model is evaluated based on several criteria, including computational efficiency, simulation speed, and scalability. Performance benchmarks may be established by comparing simulation results with those obtained using traditional modeling approaches (e.g., sequence components) to quantify the advantages of dynamic phasor modeling in terms of accuracy and computational efficiency.

5. Conclusion:

Unbalanced radial distribution systems pose unique challenges for modeling, analysis, and control due to their asymmetrical configurations and dynamic behavior. In this study, we proposed a dynamic phasor-based modeling approach tailored specifically for unbalanced distribution networks, aiming to bridge the gap between steady-state analysis and dynamic simulation. Through comprehensive theoretical development, implementation, and validation, the efficacy of the proposed approach has been demonstrated in capturing the transient behavior, voltage dynamics, and control strategies in unbalanced radial distribution systems.

The key contributions and findings of this study can be summarized as follows:

Dynamic Phasor Modeling: The proposed approach leverages dynamic phasor theory to extend the traditional phasor representation to incorporate time-varying effects and transient responses in unbalanced distribution systems. By formulating dynamic phasor equations for system components, including loads, generators, transformers, and network elements, the model accurately captures the dynamic behavior of unbalanced radial networks.

Simulation Environment: An integrated simulation environment was developed to implement the dynamic phasor-based model and conduct transient analysis of unbalanced distribution systems. The simulation platform provides the necessary computational capabilities and simulation features to simulate transient events, control strategies, and system responses under varying operating conditions.

Validation and Verification: Rigorous validation and verification were performed to assess the accuracy and reliability of the dynamic phasor-based model. Validation tests against field measurements, real-world data, and benchmark models demonstrated the model's ability to accurately replicate system behavior and transient phenomena in unbalanced radial distribution systems.

6. Results

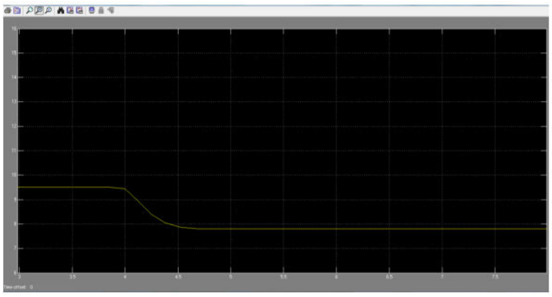


Figure 1: \Induction machine stator armature current

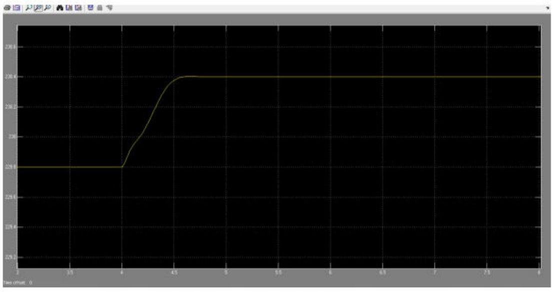


Figure 2:VG RMS

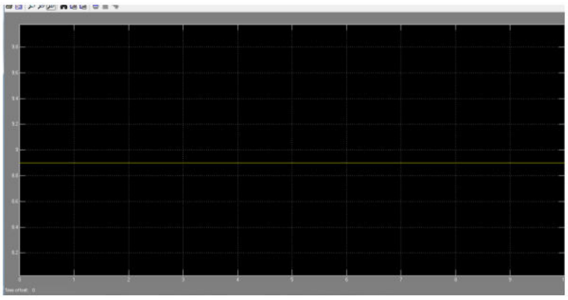


Figure 3:IPV

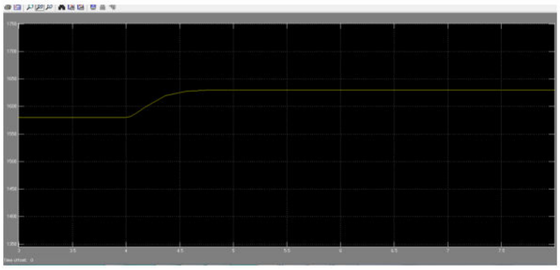


Figure 4 : ROTOR SPEED

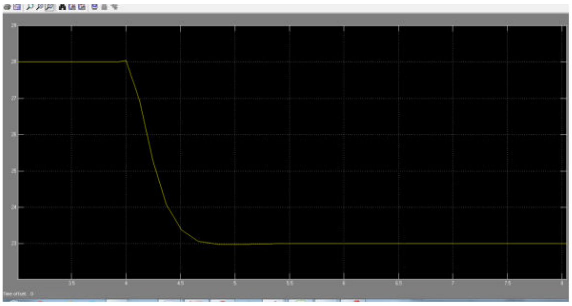


Figure 5:Electromagnetic torque

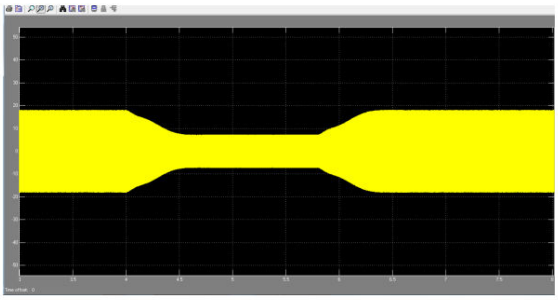


Figure 6:IPV

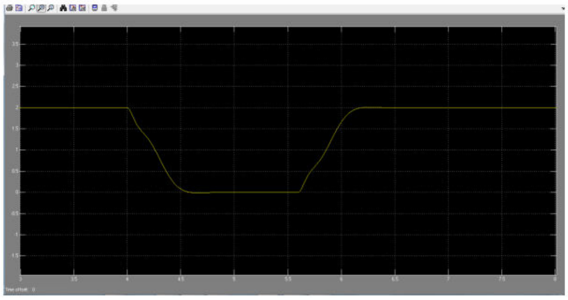


Figure 7: P PV

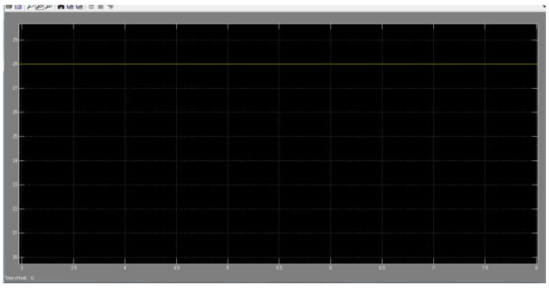


Figure 8 :Electromagnetic torque(te)

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