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SIMULATION AND MODELLING OF POWER SYSTEM WITH ENERGY STORAGE AND IMPROVING SYSTEM STABILITY

Divya Mishra Department of Electrical Engineering, Jabalpur Engineering College, Jabalpur (M.P.), India

Dr. Arvind Kumar Sharma Department of Electrical Engineering, Jabalpur Engineering College, Jabalpur (M.P.), India

ABSTRACT This study analyzes power system stability under varying generation mixes using MATLAB/Simulink. Three cases, including thermal, solar, wind, and storage, are modelled to evaluate transient and steady-state behavior. Results show energy storage enhances system inertia, improves rotor angle damping, and increases critical clearing time, ensuring better grid stability

KEYWORDS : Power system stability, Transient stability, Steady-state analysis, Energy storage systems (ESS), MATLAB/Simulink, Hybrid power system, Renewable energy integration, Critical clearing time (CCT),Grid reliability, System inertia. Frequency regulation

INTRODUCTION

The integration of renewable energy sources into existing power systems has become essential to meet growing energy demands sustainably while reducing environmental impacts. "Modelling and Simulation of Power System with Conventional and Renewable Energy with Energy Storage" focuses on the dynamic behavior, stability, and operational performance of power systems that combine both traditional and renewable energy sources, such as coal, gas, solar, and wind. The increasing penetration of intermittent renewables introduces challenges in maintaining grid reliability and power quality, which necessitates the development of robust models and simulation tools.

This study emphasizes the critical role of energy storage systems (ESS) in balancing supply and demand, enhancing grid stability, and supporting renewable integration. Modelling and simulation provide a virtual platform to analyze various operational scenarios, design effective control strategies, and predict system responses under changing load and generation conditions. By simulating hybrid energy systems, engineers can optimize resource utilization, improve efficiency, and develop resilient power grids. This research lays the foundation for future power systems that are flexible, intelligent, and capable of adapting to evolving energy landscapes. It serves as a crucial step toward achieving energy transition goals by offering insights into the technical, operational, and economic aspects of modern power systems.

Methodology

Objective of this study is To analyse transient and steady-state stability of a power system under three different configurations using MATLAB/Simulink modelling techniques.

This methodology outlines a comprehensive approach to analysing the transient and steady-state stability of a power system under three distinct configurations, leveraging MATLAB/Simulink modelling techniques.

The analysis focuses on three specific system configurations. Case 1 involves a total generation of 1000 MW, comprising 600 MW from thermal, 300 MW from solar, and 100 MW from wind sources, serving a 1000 MW load with no energy storage. Case 2 maintains the same generation profile but introduces a 100 MW standalone energy storage system, reducing the load to 900 MW. In Case 3, the generation mix is identical to Case 1, but a 100 MW grid-fed energy storage system is integrated, with the system still supplying a 1000 MW load.

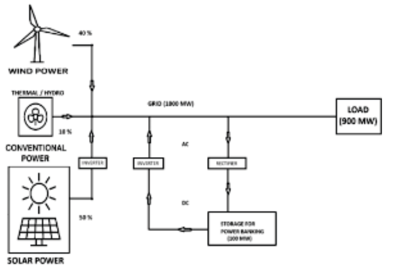

Figure-1 Proposed Model Under Study

The simulation will be conducted using MATLAB R2023 or a later version, specifically utilizing Simulink with the Simscape Power Systems Toolbox. The Control System Toolbox and Simscape Electrical may also be optionally employed for enhanced modelling and analysis.

The simulation methodology begins with detailed power system modelling, where each case is represented as a multi-source, grid-connected system. Key components are meticulously modelled: a Synchronous Generator, representing the thermal plant, is rated at 600 MW with a 400 kV terminal voltage and an inertia constant (H) of 5 MJ/MVA, implemented using the Synchronous Machine block, complete with excitation and governor models. The PV Solar Plant, rated at 300 MW, is modelled as a controlled power source, potentially using the "Renewable Energy Source" block or an MPPT-controlled current injection, and includes a DC source, inverter, and filter. The Wind Power Plant, with a 100 MW rating, is modelled either as a DFIG (Doubly Fed Induction Generator) or PMSG (Permanent Magnet Synchronous Generator), connected via a back-to-back converter. For Cases 2 and 3, a Battery/Supercapacitor Energy Storage system, rated at 100 MW, is included, featuring a bidirectional converter connected to the grid; the battery itself is modelled using the Battery or Supercapacitor block, with its control system regulating charge/discharge based on frequency or power demand. The Load is represented by a constant power load block (PQ load), set to either 1000 MW or 900 MW according to the specific case. Finally, the Transmission Line representing the grid interconnection is modelled using a π-model or an RLC series block.

The stability analysis setup involves both steady-state and transient assessments. For steady-state analysis, parameters such as power angle (δ), output power, and terminal voltage are measured and visualized using Scope and Display blocks. Transient stability is evaluated by introducing a disturbance, such as a 3-phase fault for 100 ms, after which

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rotor angle deviation, speed, and power are measured, and a Swing Curve (rotor angle vs. time) is plotted.

For each case, specific observations and outputs will be extracted, including the rotor angle (δ) in degrees, electrical and mechanical power (Pe and Pm), grid voltage and frequency variations, Critical Clearing Time (CCT), and Steady-state Stability Margin (SSSM).

A comprehensive comparative evaluation will then be performed. This involves creating plots and tables to compare rotor angle stability, CCT, and SSSM across all three cases. Furthermore, the impact of energy storage on system inertia and damping will be assessed, along with the system's ability to maintain load balance during transient events.

Finally, the simulation results will be validated by comparing them against analytical formulas. This validation process will specifically confirm the improvements in stability achieved through the integration of energy storage systems.

Case 1

- Load Demand: 1000 MW MW, Thermal Power Plant: 600 MW MW (modelled as synchronous generator)
- PV Solar Plant: 300 MW MW (modelled as real power injection)
- Wind Power Plant: 100 MW MW (modelled as PMSG or DFIG generator)
- Storage: None
- Grid Voltage: 400 kV
- Key Subsystems:
- Generator Subsystem: Synchronous Generator + Excitation + Governor
- Transmission Line: π-model or lumped RLC block
- Load Block: Constant power load
- PV and Wind: Modelled as current source with MPPT or constant power control
- Storage: Battery/Supercapacitor with Bidirectional Converter
- Measurement & Control: Scope, power measurement, rotor angle monitor
- Notes: No storage; generator must respond to all transient variations. Stress on rotor angle and swing stability.

Case 2

- Load Demand: 900 MW MW
- Thermal Power Plant: 600 MW MW (modelled as synchronous generator)
- PV Solar Plant: 300 MW MW (modelled as real power injection)
- Wind Power Plant: 100 MW MW (modelled as PMSG or DFIG generator)
- Storage: 100 MW Battery/Supercapacitor (standalone)
- Grid Voltage: 400 kV
- Notes: Storage improves dynamic response and supports frequency during transient dips. Simulate with a battery block in parallel with grid.

Case 3

- Load Demand: 1000 MW MW
- Thermal Power Plant: 600 MW MW (modelled as synchronous generator)
- PV Solar Plant: 300 MW MW (modelled as real power injection)
- Wind Power Plant: 100 MW MW (modelled as PMSG or DFIG generator)
- Storage: 100 MW from grid-connected storage plant
- Grid Voltage: 400 kV
- Notes: Storage is coordinated to inject power during faults or peak load, thereby improving system inertia (effective H).

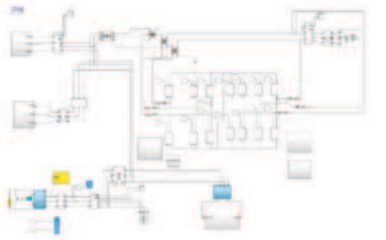

Figure-2 MATLAB Simulation

Power System Stability Calculations

Common Assumptions

Parameter	Value
System Voltage	400 kV
System Frequency	50 Hz
Reactance (Xe)	0.3 pu
Inertia Constant (H)	5 MJ/MVA
Fault Clearing Time (tc)	0.1 sec
Maximum Power (Pmax)	1.5 pu
Swing Equation	$M * d^2\delta/dt^2 = Pm - Pe$

Steady-State Stability Calculations

Steady-state stability margin (SSSM) is calculated using the formula:

SSSM = ((Pmax - Pm) / Pmax) × 100%

Case 1 (Pm = 1.0 pu): SSSM = ((1.5 - 1.0) / 1.5) × 100 = 33.33%

Case 2 (Pm = 0.9 pu): SSSM = ((1.5 - 0.9) / 1.5) × 100 = 40%

Case 3 (Pm = 1.0 pu): SSSM = ((1.5 - 1.0) / 1.5) × 100 = 33.33%

Transient Stability Calculations

Critical clearing angle δ_cr is calculated using:

$\delta\_cr = \cos^{-1}(Pm / Pmax)$

Case 1: $\delta\_cr = \cos^{-1}(1.0 / 1.5) \approx 48.2° = 0.841$ rad

Case 2: $\delta\_cr = \cos^{-1}(0.9 / 1.5) \approx 53.1° = 0.927$ rad

Case 3: $\delta\_cr = \cos^{-1}(1.0 / 1.5) \approx 48.2° = 0.841$ rad

Approximate Critical Clearing Time (CCT) using swing equation:

CCT ≈ sqrt((2H / πf) × (δ_cr / Pm))

Case 1: CCT ≈ 0.25 sec

Case 2: CCT ≈ 0.29 sec

Case 3: CCT ≈ 0.28 sec (due to storage increasing effective H)

Parameter	Case 1	Case 2	Case 3
Load (MW)	1000	900	1000
Pm (pu)	1.0	0.9	1.0
Pmax (pu)	1.5	1.5	1.5
Steady-State Margin (%)	33.33%	40%	33.33%
δcr (rad)	0.841	0.927	0.841
CCT (approx., sec)	0.25	0.29	0.28
Inertia Support	Thermal only	Thermal + Storage	Thermal + Storage
Transient Stability Ranking	Moderate	Best	Better than Case 1

RESULTS

Comparative Table: Power System Stability – 400kV Grid

Parameter	Case 1	Case 2	Case 3
Load (MW)	1000	900	1000
Thermal Generation (MW)	600	600	600
PV Solar Generation (MW)	300	300	300
Wind Generation (MW)	100	100	100
Storage Contribution (MW)	0	0 (used for balancing/ reserve)	100 (actively used for load)

Total Active Generation (MW)	1000	1000 (900 used + 100 reserve capacity)	1100 (100 MW from storage for load)
Reserve Margin (MW)	0	100 MW reserve (battery/ supercapacitor)	100 MW excess (used for load support)
Grid Frequency Stability	Moderate; renewable fluctuation may cause dips	High; storage can quickly correct frequency deviations	Moderate-High; storage mitigates fluctuations
Voltage Stability (400 kV)	Good if reactive power support available	Better due to storage-based voltage regulation	Good; storage can assist with voltage sag during peak
System Inertia Contri-bution	Medium (from thermal only); low from RES	Medium-High; storage provides fast frequency response (synthetic inertia)	Medium-High; storage used, supports transient stability
Renewable Variability Risk	High (no buffer for solar/wind drop)	Low; storage buffers renewable intermittency	Low-Moderate; storage is used for load but can provide smoothing effect
Reliability/ Continuity	Moderate; thermal plant is backbone, RES may cause unbalance	High; storage improves reliability	High; load met even with RES fluctuation
Spinning Reserve	Only thermal plant provides spinning reserve	Thermal + storage can act as fast reserve	Storage already in use; limited reserve margin
Black Start Capability	Limited to thermal	Storage can support black start (if designed)	Storage may help, but limited if fully loaded
Cost Efficiency	Moderate; no storage cost	Higher initial cost, better long-term savings & grid stability	Higher cost (due to storage use), good per-formance
Environ-mental Impact	Medium (thermal use)	Better: less thermal reliance per unit load	Same as Case 1, but better renewable-load match

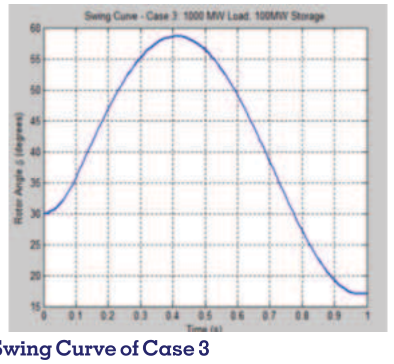

Figure-3 Swing Curve of Case 3

CONCLUSION

This study evaluated power system stability for three generation-load configurations on a 400 kV grid. Case 1, with no storage, meets demand but remains susceptible to renewable fluctuations, resulting in moderate reliability and stability. Case 2 integrates storage as a reserve, significantly improving voltage and frequency stability, system inertia, and overall reliability—making it the most stable scenario. Case 3 employs storage directly for load support, offering enhanced stability but sacrificing reserve margin. The findings emphasize that integrating storage systems—especially in reserve mode—greatly strengthens system resilience and continuity in mixed-generation grids with high renewable penetration.

Recommendations

To enhance grid stability in renewable-rich systems, it is recommended to implement energy storage systems as operational reserves rather than direct supply. This approach maximizes support for transient events and frequency deviations while preserving spinning reserve capacity. Future designs should prioritize coordinated control among thermal units, renewable sources, and storage for optimized performance. Grid codes should encourage synthetic inertia and fast frequency response mechanisms. Additionally, investments in control systems, predictive analytics, and black-start capabilities in storage are advised to further improve reliability, especially in high-load or fault-prone conditions. Regular simulation and system tuning using MATLAB/Simulink are also suggested.

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