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Utilizing Hybrid Renewable Energy Systems for Enhancing Transient Stability in Power Grids: A Comprehensive Review

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ABSTRACT

The escalating demand for energy in recent years has been met with significant challenges, including resource scarcity and stringent environmental laws, which have curtailed the expansion of power generation and transmission capacity. As a result, the load borne by certain transmission lines has notably increased, which in turn raises concerns about the system's transient stability (TS). The rapid growth of renewable energy sources in power networks further compounds this issue. Despite sharing similar penetration levels, different renewable energy sources, such as wind and solar, and their combinations can have varied impacts on the system's TS. This paper conducts a comprehensive review of recent research and developments in power system TS. The focus is on the utilization of hybrid generating systems to address TS issues. The aim is to understand how different types of hybrid systems can enhance transient stability, with a comparative analysis on the advantages and disadvantages of each strategy. Furthermore, the role of Flexible AC Transmission System (FACTS) devices in improving transient stability is examined, along with the potential for synergistic use of both methods.

1. INTRODUCTION

Transient stability enhancement (TSE) is vital for power system safety and stability. Because the electrical power system has grown in size and complexity, it is prone to rapid fluctuations in demand levels. So, stability is an essential concept that defines how well the power system operates. Therefore, transient stability analysis has become one of the most critical studies in the power system to ensure system stability in the event of severe disruption [1, 2]. New components like power electronics, electric cars, and renewable energy sources complicate power system dynamics. This requires rapid, accurate TSE. Several methods for evaluating transient stability enhancement exist, such as TSE's data-driven, hybrid system, artificial intelligence (AI) method, time domain simulation and direct method. TSE's data-driven methodologies have grown popular due to the rapid growth of artificial intelligence technology, and many research findings have been created. Thus, relevant researchers must critically analyze TSE's data-driven methodologies to comprehend the field's research state, essential technologies, and obstacles. Table 1 shows four kinds of current methods: time-domain simulation [3], direct method [4], data-based artificial intelligence (AI) method [5], and Hybrid system [6, 7]. Three nonlinear controllers are proposed [7, 8]:

(1) FLC (fuzzy logic controller)
(2) SNC (static nonlinear controller)
(3) ANFIS (adaptive neuro fuzzy inference system), Based on variable resistive type fault current limiter (VR-VFCL).

During network failure, VR-FCL resistance generation can improve the TS of a hybrid power system synchronous generator –wind turbine -photovoltaic (SG-WIND-PV). A multi-front asymmetric method is suggested for power system dynamic modelling DAEs [9]. The transient simulation may create super-real-time simulations for massive power systems using these technologies.

Table 1. Different TSE approaches' principles, merits, and weaknesses

Methods	Principles	Merits	Weaknesses
Hybrid System	Penetration of hybrid systems enhances TS	It is the most profitable way to reduce traditional energy sources	It is expensive and intermittent due to renewable energy sources. Low-power
Artificial Intelligence (AI) method	Use a trained TSE model to assess upset system stability	It has a significant capacity for learning and computes quickly	It is incomprehensible and insensitive to topological changes
Time Domain Simulation	For upset power system dynamics, solve differential-algebraic equations	Scalable, accurate, and reliable	System model and parameter correctness affect computing results
Direct Method	Create an energy function for the power system TS	It computes quickly and provides a stable margin	The energy function is hard to develop and conservatively computed

The work in study [10] doing a direct TSE analyzes on a power system using Lyapunov theory energy functions. Jafarzadeh et al. [11] demonstrate power system TS evaluation using the Koopman model. This methodology can test system stability and does not require complicated time-domain modelling after a fault. Navinchandran et al. [12] offers FCL (fault current limiter) and static var compensator (SVC) to improve facility TS and dynamic performance for system disturbance and voltage regulation. The scientific work [13] analyzes how the Fuzzy-SVC controller affects system TS. Double feed induction generator (DFIG) based grid-integrated wind farm with an active low voltage ride through (LVRT) is implemented. In terms of voltage drop, behaviours of the system, both with and without active control LVRT are examined in study [14]. Figure 1 depicts the active LVRT's rotor circuit control loop.

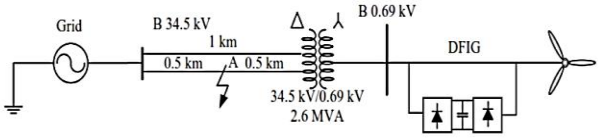

Figure 1. LVRT active rotor control loop

Kawabe et al. [15] presented a new excitation control mechanism for SGs to increase power system TS. Figure 2 shows the suggested control technique block diagram. Controlling the synchronous generator (SG) excitation voltage using the suggested wide area measuring system (WAMS) improves power system TS.

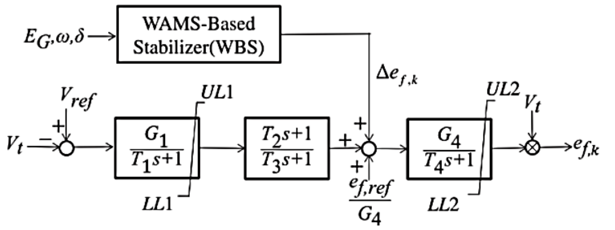

Figure 2. Diagram of WAMS control technique

The work in the study [16] power generators RPGs share accelerating suggested a hybrid measurement simulation (M–S) method for transient stability assessment (TSA) and emergency control systems. Figure 3 shows the TS margin. Deviation energy (DE) was used to rapidly assess the TS of a single machine infinite bus (SMIB) based on the deviation between the simulated running trajectory and the comparable online path.

After perturbations, the rotor angle transient process split into an initial swing and multiple swings; subsequently, system stability and virtual inertia were evaluated virtual inertia is a control algorithm, renewable energy source (RES), energy storage system's (ESS), and power electronics combination that simulates the inertia of a typical power system. It can provide dynamic inertia support by altering the active power reference of an energy storage system's (ESS) power electronic converter. This increases the system's response and stability during frequency events. Renewable power generators (RPGs) share accelerating power with synchronous generators (SG) and supply deceleration power to lessen the rotor angle difference while the initial swing phase is under virtual inertia control [17]. Virtual inertia is a component of virtual synchronous generators that uses a power injection mechanism to compensate for the absence of inertia where, the large-scale renewable energy sources (RESs) like wind and photovoltaic (PV) power plants lessen fossil fuel reliance, unlike the time domain simulation approach, direct method, and data-based integration. Thus, hybrid powertrains like wind generators, solar cells, and batteries will gradually replace traditional synchronous generators (SGs) to increase power system TS, reducing system inertia.

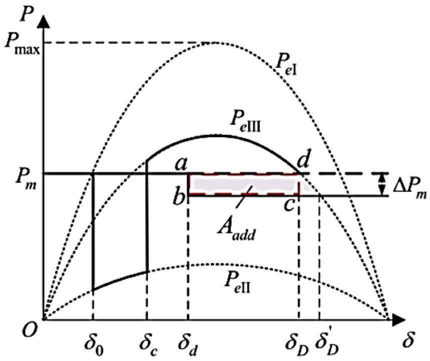

Figure 3. Power angle diagram including TS margin

1.1 Transient stability assessment

A power system's stability may be assessed by obtaining the system response trend during a fault occurrence. Time domain simulation (TDS), direct, and hybrid techniques are used to forecast TS, as shown in Figure 4 [18].

1.1.1 Time domain simulation method

The TDS approach is accurate if the system model is valid, but it requires multiple integration operations for each defect, which is computationally expensive and impractical for real-world applications [19].

1.1.2 Direct methods

Direct TSA approaches include equal area criterion (EAC), expanded EAC (EEAC), and energy function techniques based on transient energy function (TEF). A direct method based on TEF constructs Lyapunov functions to evaluate transient energy and system stability. In contrast, the EEAC methodology (an extension of the EAC approach) is a graphical solution used to develop single-machine infinite bus (SMIB) stability. The EEAC approach requires oversimplification due to SMIB, making it unsuitable for complicated linked power systems. The TEF approach could only forecast stability based on the first swing; therefore, the stability investigation will be wrong if the second swing becomes unstable [20].

1.1.3 Hybrid method

The hybrid technique uses the TDS to compute the actual system trajectory and the TEF to generate a DSA (dynamic security assessment) stability index [21].

Classical TS prediction approaches fail in real-world TSA. Quick and reliable TSA procedures must be developed to ensure power system stability. Table 2 compares TSA's traditional approaches.

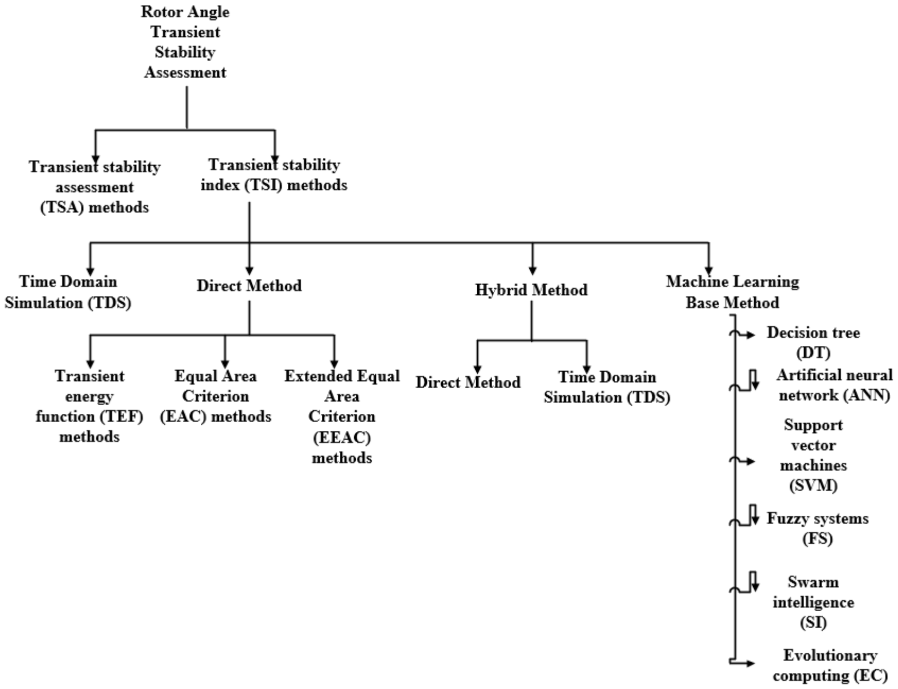

Figure 4. Power system TSA assessment methods

Table 2. TSA classical methods comparison

TSA Classical Methods	**Merits**	**Weaknesses**
Time Domain Simulation	Accurate unlike direct technique, reliable and adaptable. Unlimited modelling volume	Computational strain Inadequate and costly Inadequate system control information Limited modelling
Direct Method	Faster than TDS - Provides system information like stability margin	Limited modelling volume No convergence Estimates
Hybrid Method	Combines TDS benefits and TSA direct procedures	Single machine equivalent instability (SIME) point determines TSA prediction unstable equilibrium point (UEP)

1.1.4 Machine learning method

Machine learning (ML)-based methods may now meet online assessment speed requirements and have appropriate model volume. Studies [22, 23] used decision tree (DT) to measure DSA. This accurate approach provided a sufficient control action for system security restoration. Today, PMUs provide fast and reliable TSA solutions based on computational intelligence (CI) for categorization and recognition.

1.1.5 Computational intelligence methods

Computational intelligence (CI) was used to forecast angle swings of linked synchronous generators following dependable contingencies to measure system stability. Swarm intelligence (SI), evolutionary computing (EC), support vector machine (SVM), fuzzy systems (FS), and artificial neural networks (ANN) are CI paradigms. Kyriakidis et al. [24] and numerous others have disputed on traditional TSA-based approach, which reports an acceptable dismissal of its practice for an extensive Security Assessment of the Power System. At the same time, CI for TSA was regarded as a possible alternative quick online TSA methodology for an extensive system.

1.2 Review of hybrid systems

Off-grid hybrid power systems provide uninterrupted electricity to consumers. Remote communities in developing nations, mainly Asia and Africa, adopt these systems. Hybrid systems are used in buildings, communities, islands, hotels, resorts, communication and meteorological towers, village schools and clinics, mountain lodges, industrial fences, and water desalination.

Wind Turbine–Photovoltaic (WND-PV) is used in 28% of applications, whereas Wind Turbine–Battery (WND-BAT) and Photovoltaic–Grid (PV-GRD) are uncommon. Photovoltaic–Diesel (PV-DSL) (21%), Wind Turbine–Photovoltaic–Diesel (WND-PV-DSL) (22%), and other Hybrid Power Systems (HPSs) are also widespread, as shown in Figure 5.

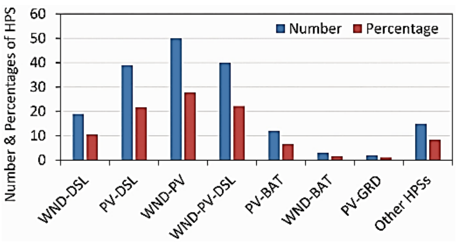

Figure 5. Review of hybrid systems

1.3 Classification of hybrid systems

Hybrid systems can be classified into four groups, which are either composed of wind generators alone or composed of photovoltaic cells or wind generators with photovoltaic cells or wind with synchronous generators or wind with storage system, or the hybrid system includes all these parts, i.e., wind generators, photovoltaic cells and batteries. Studies [17, 25] demonstrated the transient stability of a power system with wind-driven induction generators under short-circuit fault. Where control of the pitch angle affects the stability of the power system. Hossain [26] presented a simple controller-based solid state fault current limiter (SSFCL R-Type) to improve DFIG-based wind generator (WG) system TS. Xia et al. [27] studied how adding wind farms and relocating them would affect the power system's TS and how wind speed would affect it. Wilches Bernal et al. [28] examined how WPP (Wind Power Plant) affects SMIB TS. Wind penetration and three reactive power control methods were discussed. Liu et al. [29] DIgSILENT modeled Danish onshore and offshore wind farms. Wind generators' impact on TS was analyzed to evaluate western Denmark's power system TS and propose an early mitigation method to maximize wind power penetration [30]. Yagami et al. [31] proposed a renewable energy-based TS control approach (RES). The wind farm frequency controls the active power source, which is the variable speed wind generator (VSWG) rotor's kinetic energy. Integration of Wind Turbines (WTs) considering the TS of the internal generator (rpm) during fault conditions as the ideal vector and WT size were also determined using SSA [32]. Studies [33, 34] introduced the exploration of TS with solar photovoltaic power production, represented by the solar photovoltaic collector model, a suitable analytical starting point for power system TS research. Chen et al. [35] presented an urgent control strategy for system stability augmentation of system components with solar and hydropower plants utilizing the EEAC concept of equal-spanned area criterion. Almutiari and Rawa [36] examined the TS analysis of the actual network under three states: overloading the system, compensating the generator's power deficiency with a (Large Scale PV) LSP station, and replacing the SG with an LSP station. Hazari et al. [37] proposed a Fuzzy Logic Controller (FLC)-based PV plant control system to improve LVRT efficiency TS. Chaiyatham and Ngamroo [38] proposed intelligent solar farm control using proportional-integral-derived (FGS-PID) controller Fuzzy Gain Scheduling to increase TS in an interconnected power system. Fuzzy Gain Scheduling sets PID control KP, KI, and KD—inverter-controlled PV model in Figure 6.

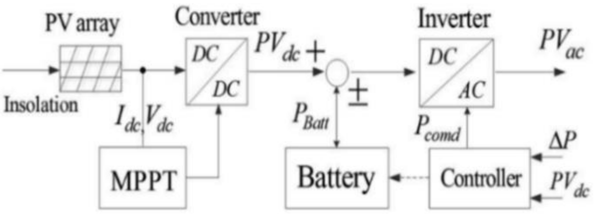

Figure 6. PV inverter model

He et al. [39] examined the TS of a DC distribution network-connected distributed photovoltaic generator and generated a variable parameter control approach. Siva et al. [40] built a hybrid PV/Wind system for TS analysis, power flow analysis, and P, Q correction in an IEEE 14 Bus system to decrease transmission losses, and fuel cost, and improve transmission line stability. Using a hybrid PSO-BFOA controller based on swarm optimization, the efficacy of wind and PV was evaluated to suppress and moderate global chaotic oscillations in a multi-machine system [41]. Hybrid Wind–PV-STATCOM uses PSO-BFOA-based intelligent VSI control (Figure 7).

As shown in Table 3 [41], most current renewable inverters are Wind-STATCOM or PV STATCOM, not Hybrid Wind-PV. This study uses a Wind-PV hybrid farm's reversible capabilities to stabilize a multi-machine power system's chaotic oscillations. Modern wind turbines have varied control capabilities that may be used to construct a new wind-PV hybrid inverter with better control.

Table 3. Tabular examination of research results on state-of-the-art algorithms (2016–2021)

Current Work	Hybrid Inverter	Wind Inverter	PV Inverter
2016 [42]			✓
2017 [43]		✓	
2018 [44]			✓
2019 [45]		✓	
2020 [46]		✓	
2020 [47]			✓
2021 [41]	✓		

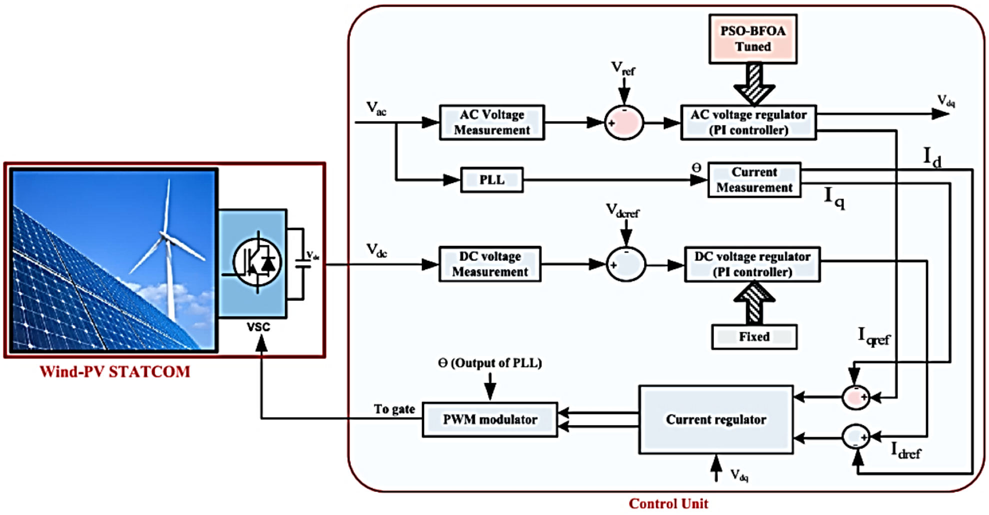

Figure 7. Hybrid Wind–PV-STATCOM PSO-BFOA-based intelligent VSI control

As shown in Table 3, Khayyatzadeh and Kazemzadeh [42] designed a conventional damping controller based on the Wide Area Measurement System (WAMS) and added it to the main control loop of a PV plant to dampen the sub-synchronous resonance SSR and to investigate the destructive effect of time delay in the distant feedback signal. The simulation results with sensitivity analysis demonstrated that the performance of the proposed TLBO-based SSR damping controller is very robust against changing the generator or power system operating point, fault length time, and PV plant generated power. Firouzi et al. [43] focused on connecting wind farms (WFs) to power systems using a unified inter-phase power controller (UIPC) to improve power system transient stability. The UIPC's power circuit is based on a normal inter-phase power controller (IPC), with two series converters and one shunt converter replacing its phase-shifting transforms. The following conclusions can be derived from the findings:

- In fault operation mode, the UIPC functions as a STATCOM coupled to the power system, capable of injecting active and reactive power.
- By controlling the reactive power control loop, the UIPC restores the CP voltage in accordance with LVRT requirements.
- By controlling the active power control loop, the UIPC controls active power of WF injected into the power system, which aids in WF stability. Varma and Maleki [44] presented a novel control of PV solar as a FACTS device STATCOM for power oscillation damping (POD) in transmission networks. The PV-STATCOM, as an alternative FACTS device, is predicted to result in significant savings for utilities looking to improve their power transmission capacity. It also creates a new business opportunity for transmission-connected solar farms to provide 24/7 STATCOM capability at a significantly cheaper cost. Two strategies for improving the transient and dynamic stability of local SG are provided [45]. During transient disturbances, the proposed controller (TC) is considered, which changes the state of the DFIG mode from generator to motor regime. ETBDC and RPBDC are also used to increase the dynamic performance of SG. The simulation results show that the proposed controllers improve both the transient and dynamic indexes of the system. When TC is employed, critical clearance time (CCT) is enhanced by nearly 1.6 times because DFIG absorbs more active power from the network during transient disruptions. Mahish and Pradhan [46] presented a technique for synchro phasor data-based control (SDC). Using multiple WFs, the suggested controller reduces the induction generator effect (IGE), torsional interaction (TI), and the SSCI effect on the series compensated network. The SDC features auxiliary SSR damping control (SSRDC) and thyristor controlled series compensation (TCSC). Silva-Saravia et al. [47] introduced a novel control strategy for dampening electromechanical oscillations in large-scale solar photovoltaic (PV) facilities. The suggested step-down modulation (SDM) control system is based on active power modulation and does not necessitate curtailment, as other approaches do. The potential of a hybrid Wind-PV farm as a STATCOM (Static Synchronous Compensator) for dampening and controlling overall chaotic oscillations in a two-area power system was demonstrated [41]. Using two PI controllers, a unique controller is used to govern the STATCOM's AC and DC currents. The PSO-BFOA swarm-based hybrid metaheuristic optimizer adjusts and manages the PI controller parameters appropriately.

For active power management of an integrated wind/solar hybrid power system under diverse disturbances, proposed a resilient partly ordered PID three degrees-of-freedom fractional order proportional–integral–derivative (3DOF-FOPID) controller [48]. Guchhait and Banerjee [49] focus on enhancing the stability of a hybrid power system model (HPSM) model with a static synchronization compensator (STATCOM) and secondary PID with filter derivative (PIDF). Jinag and Zhang [50] introduces a Superconducting Magnetic Energy Storage SMES unit into a wind farm power system to improve TS. Hemmati et al. [51] introduced a time-varying unbalanced load management technique for double-feed wind turbines (DFIG). DFIG includes batteries, Thyristor-Controlled Reactors (TCRs), and TSCs. Hazari et al. [52] suggested RESS, where a Variable Speed Wind Turbine with a Double Feed Induction generator (VSWT-DFIG) feeds its kinetic energy (KE) during generating outages to stabilize traditional SGS. The hybrid system consists of DFIG, PV plant and SGS. Mohanty et al. [53] exammed TS and issues with compensating for reactive power in wind, diesel, and PV (HS) Hybrid System with a Fuzzy-Slip-Mode-based Unified Power Flow Controller (UPFC).

2. LITERATURE REVIEW

Wind energy was the most promising renewable resource for widespread power generation until 2009. Due to semiconductor and power electronics developments, solar PV and wind energy have become promising sources of bulk electricity generation since 2009. Figure 8 compares global PV and wind power growth 2000–2023, actual and forecast. Figure 8 shows that PV outgrew wind after 2019.

Most of the researches needs to consider the use of the hybrid system to improve the TS, as shown in Figure 9.

Table 4 summarizes research that has studied the improvement of TS using hybrid systems with improvement methods.

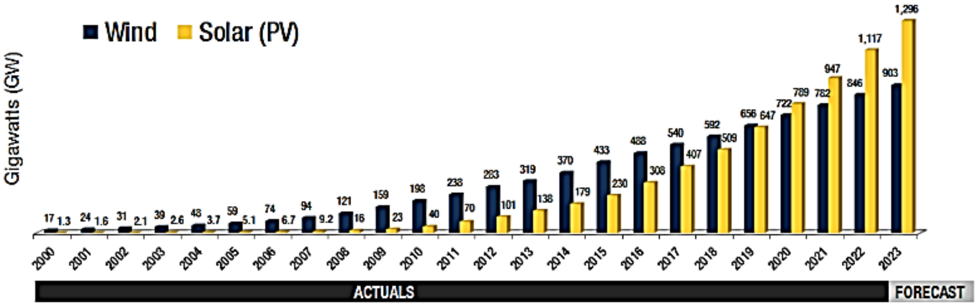

Figure 8. Comparison of PV and wind installed capacity [54]

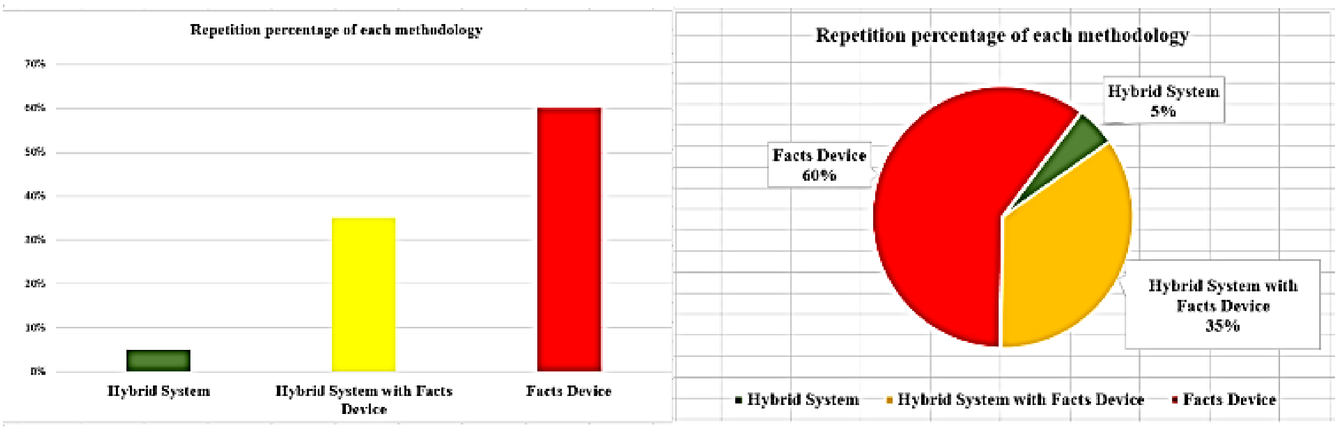

Figure 9. Each methodology's repetition percentage

Table 4. Principles, benefits, and drawbacks of hybrid TSE approaches

Reference	Principles	Benefits	Drawbacks
[55]	Utilization of a novel control strategy for the battery energy storage system (BESS) utilizing wide-area data	It may coordinate the active and reactive power injection of the BESS to optimize its converter capacity for the increase of stability	Costly and does not examine voltage stability
[56]	virtual synchronous machines (VSM) improved PV-hydro microgrid TS	VSMs increase TS by reducing frequency fluctuations and high-frequency change rates owing to irradiance or load changes	VSM energy storage is poor compared to system size. VSM converters have high power handling needs, which might increase system cost
[57]	A novel control method for rotor-side converters (RSCs)	During the fault state, the proposed RSC controller of the DFIG delivers an adequate amount of reactive power to the squirrel cage induction generator (SCIG) to keep the overall system stable	Wind turbine location and penetration are ignored
[58]	Wide area control (WAC) Design for TS enhancement (DFIG)	RL-based WAC improves system responsiveness. WACs damp area oscillations quicker, increase CCT, and tie-line stability margins	It does not take location and penetration level
[59]	New intelligent damping controller (NIDC) for STATCOM to improve hybrid system TS	The suggested controller improves damping and TS under abnormal conditions	It does not take location and penetration level
[60]	PI controllers with PSS and FACTS-based stabilizers in a multi machine power system with PV and wind farms increase power system stability. Adaptive velocity update relaxation particle swarm optimization (AVURPSO), gravitational search algorithm (GSA), and genetic algorithm (GA) optimized the proposed FACTS, PSS, and PI controller parameters	Static synchronous series compensator (SSSC) and power system stabilizer (PSS) LVRT simultaneous controllers reduce oscillation and temporal damping, and the AVURPSO algorithm outperforms GSA and GA, where they are the most dependable and effective LVRT capability augmentation solutions for wind and PV farms	Employing FACTS devices to increase TS instead of hybrid systems and studying one kind of faults
[61]	Wind turbines and PV arrays improve hybrid power system TS	PSS4C suppresses low-frequency oscillations better than GPSOPSS4B and PSS4B	Using one PV array and one wind turbine, it can use more than one
[62]	Employing interval type-2 fractional order fuzzy PID (IT2FOFPID)-based power system stabilizer (PSS) to reduce low-frequency oscillations and increase TS	Resilient performance compared to the particle swarm optimization (PSO)/ firefly algorithm (FA)/ hybrid genetic algorithm and bacterial foraging optimization (hGABFO)/ hybrid differential evolution and pattern search (hDEPS) optimized IT2FOFPID PSSs under different loadings and fault scenarios	Adoption of one type of fault for the study
[63]	Four control options are evaluated to improve grid-connected PV system LVRT	It improves LVRT capabilities and power system TS	Study normal conditions
[64]	Optimum shunt-resonance fault current limiter (SRFCL) design to increase grid-connected hybrid PV/wind power system TS and fault ride-through (FRT) capabilities	Improve hybrid system TS under all faults. Hybrid system active power and grid voltage increase	Ignores location and voltage profile

As shown in Table 4 [55], the usage of BESS (battery energy storage system) for transient stability improvement was examined, and a novel control technique for the BESS employing wide-area information was proposed. To apply to multi-machine power systems, the control technique employs two stability indices, the energy function and the rotor speed of the critical machine. Furthermore, it can coordinately control the BESS's active and reactive power injection to make maximum use of its converter capacity for stability enhancement. Tamrakar et al. [56] presented The potential use of virtual synchronous machines to increase the transient stability of PV-hydro micro grid systems. PV penetration can be increased by simulating inertial needs with VSMs. VSMs can reduce frequency variations and the high rate of frequency change caused by irradiance or load changes within specified limits. Akanto et al. [57] demonstrated a novel rotor-side converter (RSC) control method, which played an important part in ensuring the LVRT's capability for a wide range of hybrid WF comprising of both fixed-speed wind turbines with squirrel cage induction generators (FSWT-SCIGs) and variable-speed wind turbines with doubly fed induction generators (VSWT-DFIGs). Furthermore, the suggested RSC controller of the DFIG was configured to provide an adequate amount of reactive power to the SCIG during the fault state to keep the overall system stable. Yousefian et al. [58] proposed a wide-area control (WAC) design to improve the transient stability of a power grid using doubly fed induction generators (DFIG). The WAC's goal is to estimate the system's global energy function independent of the contingency and derive supplemental damping control to complement the synchronous generator excitation system and local active and reactive power control of the DFIG. Ou et al. [59] attempted to use a novel intelligent damping controller (NIDC) for the static synchronous compensator (STATCOM) to reduce power fluctuations, voltage support, and damping in a hybrid power multisystem. The results of the tests reveal that the suggested controller has improved damping properties and can successfully stabilize the network under unstable conditions. Movahedi et al. [60] recommended the use of PI controllers in PV and wind farm controllers, as well as a combination of PSS and FACTS controllers, the coordination of which is critical. The PSS, FACTS, and PI controller design problems are formulated as optimization problems, and the adaptive velocity update relaxation particle swarm optimization (AVURPSO) algorithm, gravitational search algorithm (GSA), and genetic algorithm (GA) are used to find the best controller parameters. These three approaches all identify the solution to a given objective function, but they use various strategies and computational efforts to do it. PSS tuning was investigated to offer damping to attenuate low frequency oscillations [61]. A wind turbine and photovoltaic (PV) array are added to an IEEE 9-bus system. ETAP simulation findings on a modified IEEE 9-bus system reveal that PSS4C can suppress very low frequency oscillations better than enhanced particle swarm optimized PSS4B (GPSOPSS4B) and PSS4B. Ray et al. [62] focused on the development of a hybrid firefly algorithm-particle swarm optimization (FAPSO) scheme for optimizing the parameters of an interval type-2 fractional order fuzzy proportional integral derivative (IT2FOFPID) based power system stabilizer (PSS) to reduce low frequency oscillations in a power system. Comparative studies show that the hybrid FAPSO optimized IT2FOFPID-PSS outperforms the PSSs based on the FA/PSO/hGABFO (hybrid genetic algorithm and bacterial foraging optimization) and hDEPS (hybrid differential evolution and pattern search) optimized IT2FOFPID approaches in various operating scenarios. To improve the LVR T capabilities of a PV station, four distinct types of control strategies are created and analyzed [63]. To examine the practicality of the proposed control strategy, a comprehensive simulation of the grid-connected large-scale PV station is performed using PSCAD/EMTDC. An ideal design of a Shunt-Resonance Fault Current Limiter (SRFCL) was developed to increase the Fault Ride-Through (FRT) capacity and transient stability of a grid-connected hybrid PV/wind power system [64]. The SRFCL design parameters are optimized using the particle swarm optimization (PSO) approach. The results show that the proposed SRFCL improves the dynamic behavior and transient stability of the hybrid power system during fault events significantly. Furthermore, when the ideal SRFCL is used, the injected active power by the hybrid system and the grid voltage profile are significantly enhanced during grid disturbances.

3. CONCLUSIONS

When looking at earlier research on the improvement of TS, most of the research took hybrid systems as study systems. This was due to the increased penetration of renewable energy sources in power systems, which was made possible by the development of power electronics. This resulted in a rise in the proportion of power systems that use renewable energy sources. The use of hybrid systems that don't have a huge inertia or batteries storage system (BSS) had a negative impact on the TS of power systems, which resulted in studying the used methods to improve TS in these systems to get a positive effect; however, studies related to the use of hybrid systems to improve TS are minimal. It is extremely rare, and as a result of these investigations, the following points were identified as potential future contributions to increase TS in future studies.

(1) Most research focused on incorporating renewable energy sources into energy systems without considering the possibility of employing these sources to increase transient stability.
(2) Most earlier studies focused on a three-phase-to-ground fault, but they should have included other types of faults that could have happened as well as all of the factors that lead to system instability.
(3) Not considering the effect of the size and the location of wind farms on TS.
(4) Since photovoltaic cells are not well equipped and are unable to provide the system with sufficient power during times of severe and sudden transient changes, the majority of the earlier studies neglected to take into account the possibility of using a photovoltaic system integrated with storage batteries to support and improve the TS of the system.
(5) Previous studies did not employ electric vehicle batteries (EVB), which may be found in huge numbers in car garages, to support and enhance the TS of the system.

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