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Analysis and Design of Synchronous Generators in Power Plants

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ABSTRACT

This paper discusses the synchronous generators as significant machines in modern-day power plants, and who they successfully convert mechanical energy into electrical energy. Such parameters of the design and performance as the number of poles, the synchronous reactance system, and excitation system that pre-condition the features of the generator working are devoted to in the study. Voltage regulation and efficiency are special considerations that are required in delivering stable and consistent integration in power grids. The experiment quantifies the dynamic stability under various conditions of load and faults through the analytical devices such as the Heffron-Phillips model. The last aim is to propose better design and control practices to enhance the performance of the synchronous generators.

1. Introduction

Thermal, hydroelectric and nuclear power plants use synchronous generators to provide the essential energy conversion and grid stability [1]. Their performance analysis and design are essential to meet the growing energy needs and incorporate renewable sources [3]. The given research examines the principles of the synchronous generator design, performance analysis, and issues in the contemporary grid environment, relying on both the modern models and control strategies [4].

1.1 Motivation, current state, and basics

We have to thoroughly examine the Slovenian power system's small-signal stability as part of our routine job. Our first comprehensive study was a local oscillations of synchronous generators of the Slovenian power system, stability of the small-scale is closely linked to (and relies upon) local oscillation modes. Examining a single power plant's rotor angle oscillations in comparison to the power system as a whole is linked to local oscillations [1]. We provide the study's findings in this publication as they are general and, in our opinion, helpful to other power system operators and researchers. Basic concepts and the present stability of the power system are summed up in the paragraphs that follow.

Power system stability is the ability of an electric power system to respond to a physical disturbance that in which most system variables are limited in such a way that nearly the entire system remains functional [1]. This ability is contingent upon the initial operating conditions of the system. There are two types of disturbances: minor ones, which indicate a load that is constantly changing, and major ones, including unplanned malfunctions and switching.

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Synchronous generators are key components of power systems. The stability issues with many synchronous generators in the electrical system have significantly increased in the last several decades. This is due to three primary factors:

synchronous generator construction modifications brought on by the need to optimize production and transportation costs. As a result, the rotor's inertia moments and damping windings have lower damping coefficients [2].

The addition of new control systems to power systems, or alterations which will necessarily arise by a changed mode of operation of power systems (e.g. operation of facilities at peak performance); achievement by new and more rigorous requirements by the transmission system operators; open access to transmission; and environmental constraints; and increased competitiveness (e.g. addition of additional voltage control systems, which the TSOs propose to control the terminal voltage of the power plant in parallel with the minus reactive power behaviour, changed primary control systems which will then be able to ensure the TSOs requirements when the generators of both islands are. The extra control systems may decrease damping and cause the power system to be unstable under certain other conditions of the operation [2].

Modern power systems are run at their maximum transmission capacity as energy demand rises, which can quickly result in a crisis scenario [3].

Because of these factors, synchronous generators in contemporary power systems are far more susceptible to power system disruptions (damages, faults, and mistakes) that make natural oscillations unstable.

The results of high stability issues are already seen through mounting cases of major blackouts in the power system in recent years. They are very important and have numerous reviews in the literature e.g. [3]. As observed, the abnormal weather conditions like extreme winds and heavy storms and the falling of trees on transmission lines had the greatest number of blackouts. Approximately half of all outages in the globe occurred in 20112019 due to these reasons. In second place after faulty equipment and human error are the cause of blackouts. During the same time frame, approximately 31.8 percent of all the world blackouts were due to these reasons. As seen in [3], the number of blackouts in 2011 was approximately 2050 and the average duration of the blackouts was 4 h. The statistics available indicate that blackouts affect the contemporary society in an exceptionally adverse way and bring about serious economic harm.

Power systems can become unstable in various ways and be affected by a very broad array of factors. Local oscillation modes and small-signal stability are both linked to rotor angle stability, according to [3].

Rotor angle stability is seen as the capability of a system of synchronous machines of an interconnected power system to remain in synchronism when a disturbing element is inserted. The investigation of the electromechanical vibrations of the power systems is the stability problem of the rotor angle. It is easier to analyse it and to gather data pertinent to the nature of stability issues by splitting it into two categories: rotor angle stability of the small-scale sense (or small, steady-state or small-disturbance or long-term or dynamic (in the USA) stability), and rotor angle stability of the great scale (or large scale, transient, short-term or dynamic (in Europe) stability).

Small-signal stability is the ability of the power system in sustaining synchronization in the presence of small disruptions. To facilitate analysis it is reasonable to linearize the system equations, as the disturbances are believed to be negligible [3]. There can be 2 instabilities, either rotor oscillations which increase in amplitude due to a lack of damping torque, or rotor angle increase through a non-oscillatory (aperiodic) mode. The major problem associated with small-scale stability in power systems today is commonly connected to a poor oscillation damping. The problem of aperiodic instability has been greatly minimized by continuously operating automated voltage regulators (AVR) [3].

The primary cause of issues with small-signal stability is synchronous generator oscillations. Some other components of the power system oscillate with the synchronous generator. We structure these oscillations into five categories: between a single synchronous generator and the rest of the power system (so-called local oscillation modes, local oscillations, local modes, machine-system modes, single-machine infinite-bus oscillations), between synchronous generators and a turbine (torsional oscillation modes), between places within the power plant (proximate to the control systems) and places within the power system (distant to the control systems) (so-called control The most common of small-signal stability problems are of the type of local oscillation modes) [4]. That is why the more specific findings of the studies of local modes are provided in the article.

1.2 Limits and purposes of this work

The primary objective of the work is a close investigation of the local oscillation modes. The work presented is the study of the oscillations in the Slovenian power system. The Slovenian electrical network consists of strong 400 kV links between the country and its neighbours, and is on a small area (20,271 km2). Its 74 synchronous generators have a nominal power that exceeds 1 MVA. Only two of them are massive (813 MVA in the nuclear power plant and 727 MVA in the thermal power plant); the nominal power of the majority of generators ranges between 10 and 40 MVA. Slovenian power system has pronounced local oscillation modes due to the small size and high dispersion of most of the generators and direct connection of the strong backbone by over block transformers and very short transmission lines.

Some of these questions that we have attempted to answer in this paper are:

- With devices 1. What are frequencies and dampings of local oscillations of various generators? Is it possible to estimate where the eigenvalues of the local oscillation modes of other generators fall?
- You can figure out how the operating point (i.e., the active and reactive power) of a generator affects the local mode eigenvalues of the generator. Does it the same thing with alternative generators (size, age, type)? What impact does the connection to the infinite bus have?
- What effect do control systems have on the local mode eigenvalues?

The value of the results obtained will be:

- Estimation (prediction without measurement) of the local oscillations.
- For the presence of measured data of existing oscillations (momentary values of generated three-phase powers and rotor speeds of generators), classify the measured oscillations in the local oscillations (and exclude them from torsional oscillations, control oscillations and inter-area oscillations);
- To avoid activities which would lead to local mode eigenvalues becoming problematical as regards stability,
- Improving the damping of these eigenvalues (PSS design is out of scope of this paper).

1.3 Current solutions and literature review

In addition to being a significant engineering issue, synchronous generator oscillations present an intriguing scientific conundrum. As a result, this field is quite active and has many publications.

For estimation and prediction of the properties of oscillations, one has to have a suitable mathematical model. Though straightforward, the local oscillation analysis can most simply be seen as a linearized model of a single machine coupled to an infinite bus (SMIB). It appeared in the model of [5] and was named, following the authors, the Heffron-Phillips model (H-P model). The model H-P was added to and changed many times. This is an evolving process, e.g., [6,7], although the simplest H-H-P paradigm is yet considered as the foundation to research work in that field. A detailed description of the analytical determination of H-P in [4,8].

A full model-based quantitative analysis of frequency oscillation of synchronous generators was first published more than 20 years ago. In [11], the author approximately estimates the frequencies of the control oscillations as being in [1.5 - 2.5 Hz], and the torsional oscillations as being in [10 - 50 Hz]. In [12] e.g., it is approximated that the local and inter-area oscillations have frequency ranges of 0.8-1.8 and 0.2-0.5 respectively. The indicative values are subject to these results. In [13], a more general introduction to sources, characteristics and analyses of natural oscillatory phenomena in power systems is provided. In this report, inter-area electromechanical modes in the ambient response have been explicitly considered.

The constructions of synchronous generators, the control concept, and the network connections have also evolved greatly since then, but we do not find in recent publications of the literature such use of the analysis of a large number of synchronous generators as to estimate the local oscillation frequencies. Another potential research gap is that no publications have been found where the anticipated damping of these vibrations is carefully appraised. The damping of a mode influences the speed at which (and whether) a modes associated with it decays. Therefore, the nearest correlated parameter is the damping [13] to the system stability. Recent publications devoted to damping of oscillations according to new solutions and equipment based on synchronous generators confirm the need of knowledge in this area. In [14], it considers the damping of the oscillations the inclusion of a photovoltaics virtual synchronous generator would have created. sub [15] explores the waveform of wind farm synchronous generators. The dynamic [16] reference gives details on how to implement energy storage system to damp electromechanical oscillations of synchronous generators. References [17,18,19] describe the effects of control appliances on the power grid frequency, power system blackouts, and cascading failures. The small signal oscillations of the synchronous motor-generator pair are unveiled and discussed in more details in reference [20]. Just one of the articles proves the topicality of the considered matter.

1.4 Influence and paper structure

We can highlight four original contributions of the paper:

- Estimations of the expected local mode eigenvalues of synchronous operating generators (boundaries of regions, in which eigenvalues of the various types of synchronous generators would lie to different operating regimes).
- The effect of the operating point of the synchronous generators on the local mode eigenvalue is examined, and rules are derived to allow the operators to determine for a given operating point under what conditions local oscillations will be weakliest damped.
- The effect of the AVR on the local oscillations is also studied.
- Experimental results, whose importance lies in corroborating the results obtained by numerical methods.

2. Synchronous generator design principles

2.1 Rotational speed and number of poles

A synchronous generator's rotational speed is primarily dictated by the correlation between grid frequency and pole count. The synchronous speed equation is used to represent this:

$$f = \frac{P \cdot N}{120}$$

where N is the mechanical rotating speed (RPM), P is the number of poles, and f is the electrical frequency (Hz) [4]. The formula emphasizes that the speed needed to maintain a specific frequency decreases as the number of poles increases. The concept is applied in numerous power generating situations. As an example, hydroelectric power plants typically employ many poles to permit low-speed operation whilst keeping grid frequency synchronization, whereas thermal power plants employ few poles to permit higher-speed turbines, and this ensures maximum efficiency and power density [1]. Thus, the selection of pole number and speed is a design optimization problem which trades off system stability, system efficiency, and system mechanical limits.

2.2 Reactance

Reactance is one of the most significant parameters of the design of synchronous generators because it influences both the steady-state and transient operation. To regulate the machines response to load variations, faults and oscillations in power systems direct-axis reactance (Xd) and quadrature-axis reactance (Xq) are the parameters that control this behavior. A large value of Xd will increase the synchronizing torque and is likely to decrease the transient stability, whereas Xq governs the ability to exchange reactive power and operate with a high voltage [7]. These reactances must be determined accurately, either by equivalent circuit analysis or by dynamic test, to be operated successfully. Heffron-Phillips model is also commonly used in small-scale stability analysis where the engineer can anticipate the behaviour of a generator under disturbances and create the necessary damping load, and control measures [6], [8]. The correct modeling and choice of values of reactance therefore guarantees healthy play in interconnected grid operations.

2.3 Excitation system

The rotor windings receive DC current from the excitation system, which creates the magnetic field required for the motor to run synchronously. Its design has a direct impact on fault response, transient stability, and voltage management. Two fundamental excitation systems are in use:

Static Exciter: This technique provides excitation current by use of rectifiers with brushes and slide rings. Although these systems are dependable, they require routine maintenance since carbon dust can cause them to fail and the brushes wear out [5].

The AC exciter of rotating rectifiers that does not include brushes or slide rings is called a brushless exciter. In large power plants, this architecture is more dependable, less serviceable, and more efficient [2].

In order to ensure rapid response and resiliency under changing grid conditions, the excitation systems of current systems are becoming more and more digitalized with control algorithms and adaptive properties [21], [22]. With the introduction of new functions that enhance the oscillation damping, e.g. power system stabilizers (PSS), the excitation systems have become a foundation of the generator design and grid stability.

3. Performance analysis

3.1 Stability in motion

Dynamic stability is the ability of a synchronous generator to continue operating in synchronization after unpredictable impairments, such as sudden variations in the load, short circuits or switching. In the case of interconnected power systems, instability is an important performance measure because it may result in cascade failures or blackouts.

The Heffron-Phillips model is the most commonly used analytical model in small-scale stability studies [5, 6, 7, 8, 9, 10]. This linearized model is the description of the generator in terms of transfer functions involving the parameters of the excitation system, the angle of the rotor, and the internal voltage. The voltage on the d-axis may be simply said to be as follows:

$$Vd=Ed-IdXd+IqXq$$

In which Id and Iq represent the direct-axis current and quadrant current respectively and Vd is the voltage across the d-axis and Ed is internal electromotive force [6].

To increase damping and prevent oscillatory instability, the excitation systems are fitted with Power System Stabilizers (PSS). These devices suppress low-frequency oscillations by modulating the exciter input due to rotor speed variation to provide smooth generator-grid interaction [11], [12].

Table 1. Key parameters for stability analysis

Parameter	Description	Typical

		Value
(Xd)	Direct-axis reactance	1.0–2.0 p.u.
(Xq)	Quadrature-axis reactance	0.6–1.2 p.u.
Damping Coefficient	Oscillation damping	0.05–0.15
Inertia Constant (H)	Rotor inertia	3–10 s

Enough inertia, proper reactance and sophisticated stabilizing controls present a combination that makes working reliable in both steady-state and transient conditions.

The horizontal axis in figure 1 shows the stability index with respect to the inertia constant (H) of synchronous generators. Inertia Constant (H): The greater the value, the more kinetic energy is stored and the more dynamic stability is enjoyed. Index of Stability: It is affected by inertia constant, damping coefficient, direct-axis reactance (Xd) with too low Xd acting against stability. Curve Insight: The stability index is growing gradually with the increase of the H between 3 and 10 s that proves higher inertia is helpful in increasing the stability falls. The analysis will help to optimize design and control strategies and will assist engineers in choosing the right kind of damping controls and configurations to ensure grid stability.

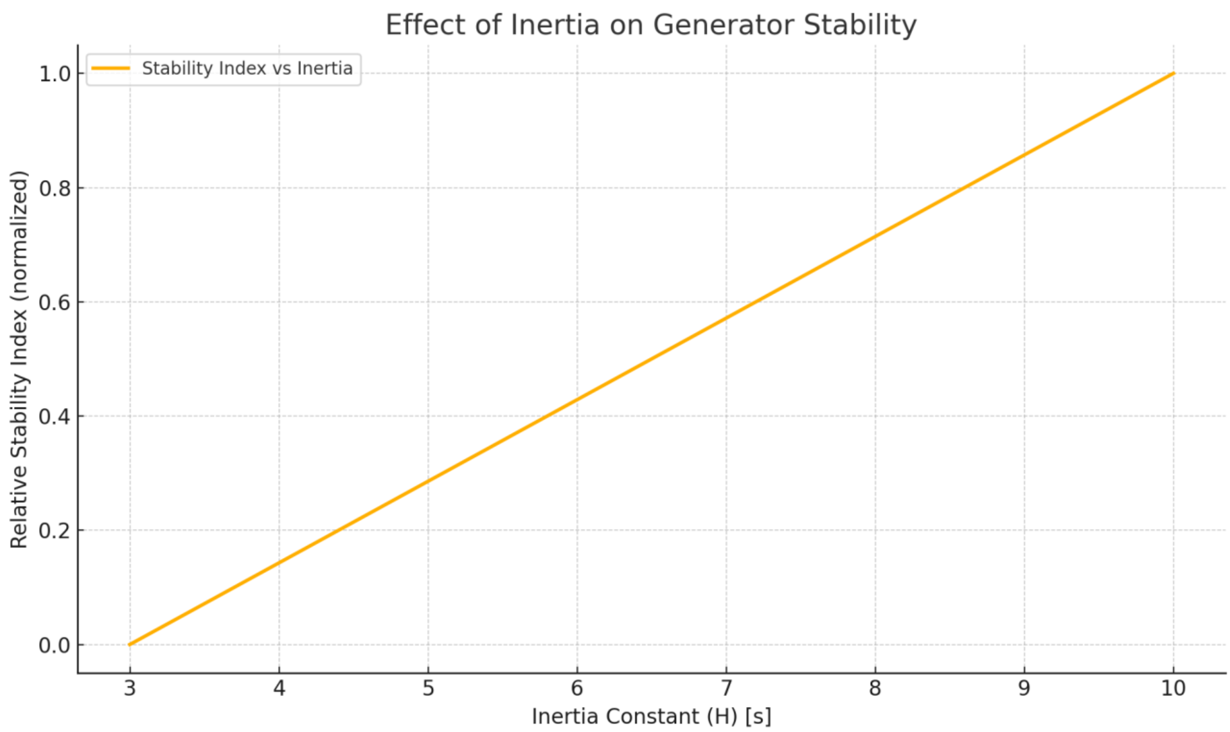

Figure 1. Stability index with respect to the inertia constant (H) of synchronous generators

This surface plot in figure 2 describes how the constant of inertia (H) and the coefficient of damping (C) affect the dynamic properties of a synchronous generator. Some important observations are: lowest possible level of inertia and damping results in peak stability, low level of inertia or damping results in reduced stability notably with high direct-axis reactance (Xd). Stability is affected negatively by variations in Xd. This visualization can be used to tune power system stabilizers, optimize settings in generators and predict how the system will behave during disturbances.

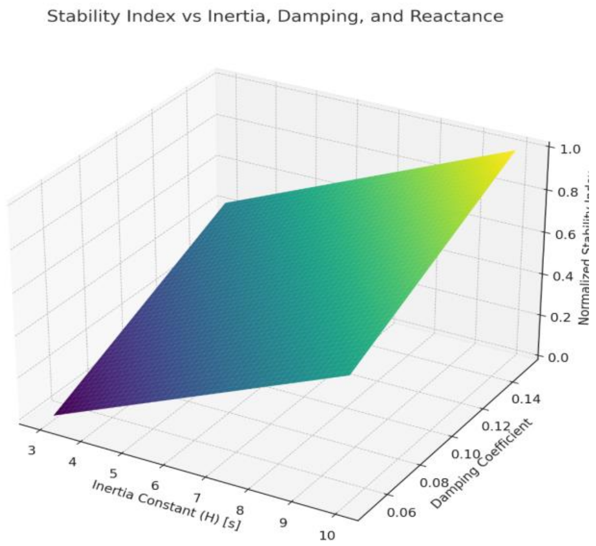

Figure 2. Constant of inertia and the coefficient of damping

3.2 Control of voltage

The ability of the generator to keep the terminal voltage in a predetermined range when the system load is changed is known as voltage regulation. Deviations may cause unstable electricity, and/or equipment failures.

Automatic Voltage Regulators (AVRs) use the exciter current to stabilize the output voltage by varying the magnetic field and adjusting the exciter current [5]. Current AVRs use digital and adaptive control algorithms to effectively deal with complex, changing grid conditions and respond quickly to perturbations [2], [20].

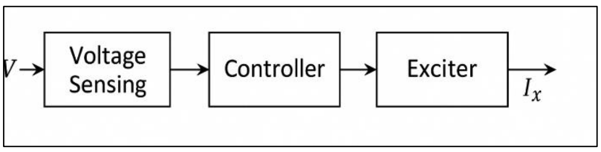

Figure 3. Simplified AVR block diagram

The AVR notices any variations in terminal voltage and modulates exciter current to maintain consistent output to produce varying loads [2].

AVRs are important in providing truthful response to real-time feedback and prompt corrective response that facilitates the maintenance of the quality of the voltage delivered by the synchronous generator particularly when the grid is weak, or overloaded.

Figure 4 reports addresses how auto voltage regulators (AVRs) respond to the deviation of the voltages. It introduces three AVR designs with varying response times: quick AVR (τ = 0.2 s) that regulates the voltage faster, a moderated AVR (τ = 0.5 s) that is balanced in its response and finally a slow AVR (τ = 1.0 s) that stags behind in the response, thus potentially leading to instability in the voltages. Another advantage highlighted in the text is the significance of feedback control to ensure stability of the terminal voltages and the way digitally adaptive AVRs make use of sophisticated algorithms to quickly respond to the changes of the voltages.

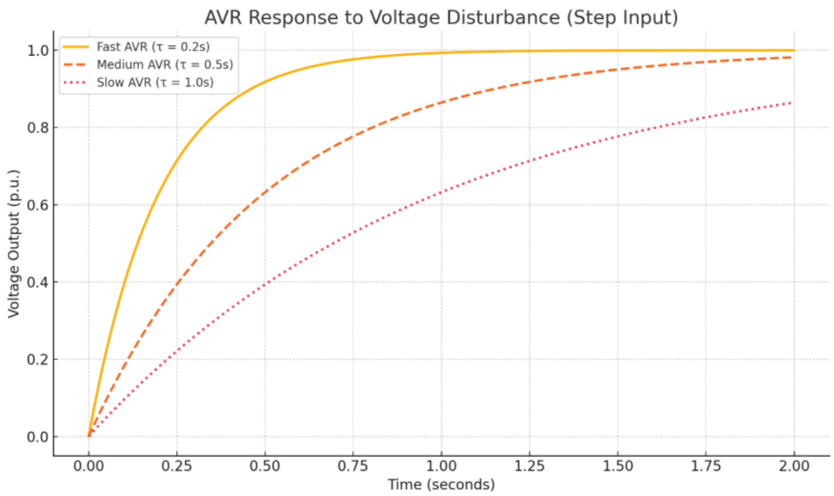

Figure 4. VR response curve: voltage control dynamics

3.3 Effectiveness

The relation of electrical output power to motorized input power is known as competence. Because augmented efficiency lowers fuel ingesting, running costs, and ecological effect, it is an essential design and operational normal.

Three types of losses are the main factors limiting generator efficiency:

- Resistance in the stator and rotor windings causes copper losses.
- Eddy currents and hysteresis in the magnetic core are the causes of iron losses.
- Mechanical Losses: Associated with windage and friction in rotating parts and bearings.

To reduce these losses, high-conductivity windings, low-loss magnetic materials, and improved cooling and bearing systems are used in modern synchronous generator designs [14].

Table 2. Typical losses in synchronous generators

Loss Type	Contribution (%)	Mitigation Strategy
Copper Loss	40–50%	Use of high-conductivity windings
Iron Loss	20–30%	Use of low-loss magnetic materials
Mechanical Loss	10–20%	Optimized bearing design, better cooling

Large synchronous generators in contemporary power plants may now attain efficiencies of over 98% because to the incorporation of sophisticated materials and design advancements.

Figure 5 includes a bar chart that shows an average of different types of losses impacting the efficiency of synchronous generators. Among the major losses, which can be mitigated by high-conductivity values in windings with copper Loss (1 - Copper Loss) = 45; by using low-loss magnetic cores, Iron Loss (1 - Iron Loss) = 25; and by high precision bearings and cooling, Mechanical Loss (1 - Mechanical Loss) = 15. General efficiency of generators is estimated to be around 85 percent, modern plans aim to up to 98 percent by better material choice. The importance of high efficiency is demonstrated and the impact that it makes includes reduced fuel use, reduced emissions and increased returns on investments in generation assets.

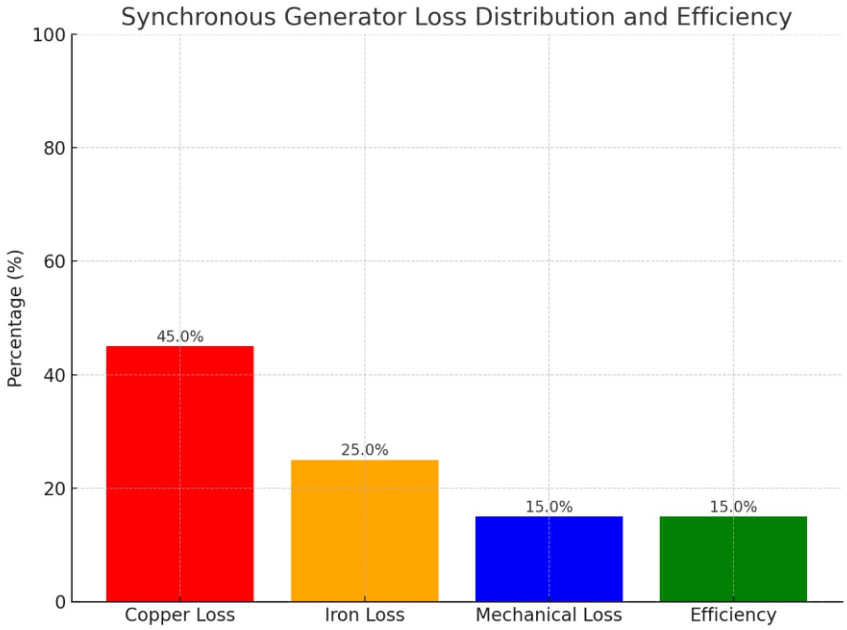

Figure 5. Efficiency and loss breakdown in synchronous generators

4. Difficulties and contemporary patterns

Synchronous generators' operational characteristics in contemporary power systems are linked to a number of difficulties that go beyond conventional design and stability issues. One of the most crucial concerns is ensuring grid resilience in the face of growing demand and more intricate networks. The present infrastructure is under stress as cities and industry grow and energy demand rises steadily. The vulnerability of power systems when synchronous generators fail to maintain stability during disturbances is highlighted by blackouts and cascade failures, which have been documented in some of the major events occurred in most of the world [18], [19]. The relevance of dynamic stability offered by synchronous generators is increased by the potential for rapid rises in voltage oscillations, frequency fluctuation, and oscillatory response after a fault event.

Another current challenge is the incorporation of renewable energy in the contemporary systems. Although not always inverters, unlike traditional synchronous generators, renewable energy sources, such as wind and solar photovoltaics, do not provide the same stability and inertia as synchronous machines. This reduction in system inertia is a drawback to both transient stability and frequency regulation and requires the more flexible and sensitive control methods of a synchronous generator to supplement frequency regulation. This has operational uncertainty due to increased penetration of renewables, which also creates more power flow variability. Synchronous generators have to be more actively operated and provided with excitation, reactive power backup, and load-sharing solutions to be able to ensure grid balance [3].

Moreover, excitation systems are getting increasingly more complex, offering opportunities and challenges. More complicated monitoring and coordination is needed where advanced excitation control is used, although it can potentially assist with transient responsiveness and voltage regulation. Other effects of poorly adjusted systems can also be instability or oscillations. The issue is the design of resilient and adaptive excitation systems, i.e. systems that respond immediately to changing network conditions and load. The Hefferon Phillips model and other stability models are useful but have to be augmented with modern computing techniques to increase their prediction capabilities.

Digital controller systems have altered the functioning of the synchronous generators in line with the current trends. Digital Excitation Control Systems (DECS) ensure that reactive power and voltage are controlled precisely and made possible advanced protection strategies. Unlike analog systems, digital platforms allow for real-time monitoring, customizable programming, and interface with supervisory control and data acquisition (SCADA) systems. This improves fault identification, improves diagnostics, and speeds up disturbance response. Digitalization also aids predictive maintenance, which reduces downtime and improves dependability by using predictive sensors and data analytics to identify potential issues [15].

As a result of digitization, the ideas of machine learning (ML) and artificial intelligence (AI) are increasingly being applied to increase the efficiency of generators [16]. AI-driven models that can learn from historical system operation data can be used with adaptive control to forecast how systems will respond to various load and fault scenarios. For instance, excitation control may be optimized using reinforcement learning algorithms to strike a compromise between stability margins and voltage regulation. The synchronous generators can be ready to react to unforeseen changes by forecasting demand variations and renewable variability using AI-based predictive analytics. AI and traditional stability models, such as Heffron-Phillips, are better applicable to real-time functions when combined.

The other contemporary trend is the move toward hybrid systems, which combine energy storage and renewable energy sources with synchronous generators. Synchronous machines serve as stability anchors in these kinds of setups, while storage devices provide fast-response balancing. Because inverter-based technology has not been able to match the inertia and fault-ride-through performance of synchronous generators, this hybridization emphasizes the continued need of synchronous generators, especially in systems with a substantial percentage of renewable sources. However, it also suggests that more sophisticated grid codes and standards are required as the coordination of control across many assets becomes more complex.

Finally, one contemporary issue with digitally controlled sync generators is computer device security. The likelihood of a cyberattack increases with the number of devices connected to digital communication networks. The stability of whole grids might be impacted by cyberattacks on protective relays or excitation systems. As a result, contemporary research is focused on more than simply improving physical architecture; it also addresses communication protocol security, intrusion detection system development, and cyberthreat resilience.

In summary, synchronous generators are now employed at the intersection of contemporary digital-intelligent systems and classical mechanical-electrical architecture. Modern trends like digital control, AI optimization, hybrid system operation, and enhanced cybersecurity help to manage the issues they face, such grid dependability, renewable energy integration, and excitation difficulties. In order to create reliable, predictable, and flexible power production systems that can meet the demands of the ever-changing global energy sources, all of these components must be combined.

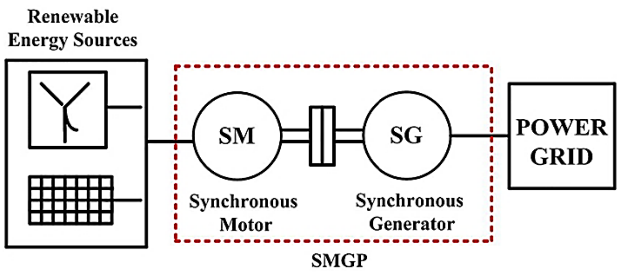

Figure 6. Integration of renewable sources with synchronous generators

Advanced control solutions are necessary because to the dynamic constraints posed by renewable sources [14].

Figure 7 explains how the integration of renewable energy increases affects the performance of synchronous generators in terms of system inertia and the stability index. Increase in the share of renewable energy reduces system inertia linearly, reaching zero at complete renewable integration, making renewable energy yet again a safety concern. On the other hand, the index of stability initially decreases as synchronous machines are displaced but begins to increase near 80% of renewable utilization because of hybrid options involving energy storage and artificial intelligence management. It suggests that supple control systems and high-level prognostication must be present in future evolving power networks, and that hybrid systems may offer a way forward in ensuring stability in decarbonized grids.

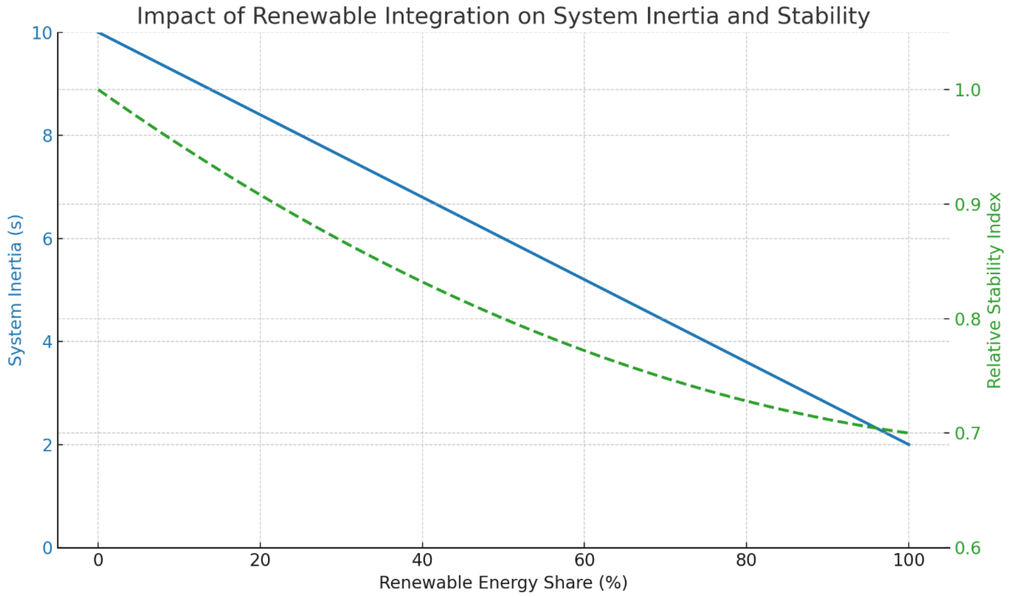

Figure 7. Impact of renewable integration on synchronous generator performance

5. Conclusions

Synchronous generators' primary benefit is that, in a power system of this century, they are the only generator type capable of providing inertia, voltage support, and reliable power conversion. Even if the share of renewable energy derived from inverters is increasing, synchronous machines continue to be the most important factor in guaranteeing system resilience and dependability. Their performance is determined by a key balance of design factors, such as excitation systems, reactance, and pole number, as well as their dynamical reaction to grid disturbances. Power engineers are able to execute more resilient operational strategies because analytical models, such as the Heffron-Phillips model, have proved crucial in understanding the operational behavior of small-signal and transient stability [7], [8].

However, issues that the synchronous generators experience are constantly changing. The integration of renewable energy sources and increasing demand is placing unprecedented burdens on operations of unstable grids that impose unprecedented risks to stability and flexibility. These issues are addressed by the increasingly common use of advanced adaptive control methods, digital excitation, and artificial intelligence (AI)-assisted optimization to address these problems. Such strategies have the potential to offer better voltage control, prediction of faults, and real time management of generator behavior. When variables are varied to enable a renewable penetration, machine learning computation can predict how the system is going to react, so that synchronous generators can adjust excitation and governor control, which reacts to reactions rather than responds to them [21].

The other important future trend is the development of hybrid power systems that integrate renewable energy resources and storage technologies with synchronous generators. These are the situations in which synchronous machines are employed to provide inertia and stability and fast-acting resources based on inverter are employed in order to regulate variability. Such a free relationship highlights the importance of the role of the synchronous generators in the decarbonized power systems.

In summary instead of becoming obsolete, synchronous generators are changing to fit into new situations. Their use in complex networks, which are to a large extent based on renewable energy sources, is changing as they are no longer the only source of electricity. More studies on high-level control measures, AI implementation, and resilient electronic systems will be necessary in order to enhance their strength and versatility. By combining intelligent technology with traditional stability models, future power systems can employ synchronous generators as smart, flexible assets for global energy security and sustainability in addition to reliable machinery.

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