INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

Enhancing Virtual Synchronous Generator Control Using ANN Based Technique

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DOI: https://doi.org/10.47772/IJRISS.2026.100600689

Received: 19 May 2026; Accepted: 24 May 2026; Published: 02 July 2026

ABSTRACT

The constant power failure in the country that had crippled business activities was caused by these factors that could not attain their respective thresholds, these factors were Frequency Deviation, Rate of Change of Frequency, Voltage Deviation, Active Power Tracking Error, Reactive Power Tracking Error, Settling Time, Rise Time Peak Overshoot and Steady-State Error. This persistent power failure was surmounted by introducing enhancing virtual synchronous generator control using ANN based technique. To perfectly achieve this, it was done in this way, virtual synchronous generator control was characterized and the causes of poor virtual synchronous generator control was established, conventional SIMULINK model for virtual synchronous generator control was designed and ANN was trained in the causes of poor virtual synchronous generator control. However, an algorithm that will implement the process was developed, a SIMULINK model for enhancing virtual synchronous generator control using ANN based technique was designed and the results obtained were validated and justified. The results obtained were the conventional frequency deviation that causes poor virtual synchronous generator control was 0.18Hz. because it could not attain the threshold of 0.2 Hz through 0.5 Hz. Meanwhile, when an ANN based technique was integrated into the system, it automatically increased by attaining the threshold 0.22Hz. and the conventional voltage deviation that causes poor virtual synchronous generator control was 6%. Meanwhile when an ANN based technique was integrated into the system, it spontaneously reduced to 5 %. Finally, with these results obtained, the percentage enhancement in virtual synchronous generator control when an ANN based technique was integrated into the system was 1%.

Keywords: enhancing, virtual, synchronous, generator, control, ANN, based, technique

INTRODUCTION

The consistent enhancement in renewable energy sources such as wind and solar photovoltaic (PV) systems into modern power grids has significantly transformed the operation al mechanism and dynamics of electrical power systems. Unlike conventional synchronous generators, most renewable energy sources are interfaced with the grid through power electronic converters, which inherently lack the rotational inertia and damping characteristics provided by synchronous machines. As a result, modern power systems experience reduced system inertia, making them more vulnerable to frequency instability, voltage fluctuations, and oscillatory disturbances (Blaabjerg et al., 2017). To address these challenges, the concept of the Virtual Synchronous Generator (VSG) has emerged as an effective control strategy for inverter-based distributed generation systems. A VSG is designed to emulate the electromechanical behavior of conventional synchronous generators by providing virtual inertia and damping through advanced control algorithms. This approach enhances grid stability and supports frequency regulation, especially in power systems with high renewable energy penetration (Beck & Hesse, 2007). The VSG control technique enables inverter-based resources to participate actively in grid support functions, thereby improving the reliability and resilience of modern power networks. Despite its advantages, the performance of conventional VSG control systems is highly dependent on the proper tuning of control parameters such as virtual inertia, damping coefficients, and governor settings. Fixed-parameter VSG controllers may not respond optimally under varying operating conditions, load changes, and network disturbances. Consequently, inappropriate parameter settings can lead to poor dynamic response, increased frequency deviations, and reduced system stability (Wu et al., 2018). The increasing complexity and uncertainty associated with modern smart grids necessitate the development of adaptive and

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intelligent control techniques capable of adjusting VSG parameters in real time. Artificial Neural Networks (ANNs), a branch of artificial intelligence, have demonstrated remarkable capabilities in nonlinear system modeling, pattern recognition, adaptive control, and optimization. ANNs possess self-learning and generalization abilities that enable them to approximate complex nonlinear relationships between system inputs and outputs without requiring explicit mathematical models (Haykin, 2009). These characteristics make ANN-based techniques suitable for power system control applications where operating conditions are highly dynamic and uncertain. Recent studies have shown that ANN-based controllers can significantly improve the performance of power electronic converters by enhancing response speed, reducing steady-state errors, and improving robustness against disturbances (Kumar et al., 2020). By integrating ANN algorithms into VSG control frameworks, it becomes possible to develop adaptive control systems capable of continuously learning system behavior and adjusting control parameters accordingly. Such an approach can improve frequency regulation, voltage stability, power-sharing accuracy, and overall grid performance under diverse operating scenarios Furthermore, the growing adoption of smart grid technologies and distributed energy resources has increased the demand for intelligent control strategies that can support autonomous and decentralized operation. ANN-enhanced VSG control offers a promising solution by combining the inertia emulation capability of VSGs with the adaptive learning capability of neural networks. This integration has the potential to overcome the limitations of traditional VSG controllers and contribute to the development of more resilient, flexible, and sustainable power systems. Therefore, there is a need to investigate and develop ANN-based techniques for enhancing Virtual Synchronous Generator control performance. Such research is expected to contribute to improving the stability, reliability, and efficiency of inverter-dominated power systems while supporting the global transition toward renewable energy integration and smart grid modernization.

METHODOLOGY

To characterize and establish the causes of poor virtual synchronous generator control

Table 1 characterized and established causes of poor virtual synchronous generator control

S/N	Performance Metric	Symbol	SI Unit	Typical Threshold/ Target Value	conventional causes of poor virtual synchronous generator control	Significance
1	Frequency Deviation	Δf	Hz	$\leq \pm 0.2$ Hz (steady-state), $\leq \pm 0.5$ Hz (transient)	0.18 Hz	Measures the ability of the VSG to maintain system frequency stability.
2	Rate of Change of Frequency	RoCoF	Hz/s	≤ 0.5 Hz/s	0.2 Hz/s	Indicates virtual inertia effectiveness during disturbances.
3	Voltage Deviation	ΔV	V or p.u.	±5% of nominal voltage	6%	Assesses voltage regulation capability.
4	Active Power Tracking Error	e_p	W	≤ 2% of rated power	1%	Evaluates accuracy of active power control.
5	Reactive Power Tracking Error	e_{φ}	VAR	≤ 5% of rated reactive power	3%	Measures reactive power regulation performance.
6	Settling Time	T_s	s	< 2 s	1s	Time required for system variables to remain within acceptable limits after disturbance.
7	Rise Time	T_r	s	< 1 s	0.5s	Indicates speed of controller response.

8	Peak Overshoot	M_p	%	< 10%	8%	Measures transient response quality.
9	Steady-State Error	e_{ss}	%	< 1%	0.6%	Indicates long-term control accuracy.
10	Damping Ratio	ζ	Dimensionless	≥ 0.7	0.9	Ensures adequate oscillation damping.

To design a conventional SIMULINK model for virtual synchronous generator control

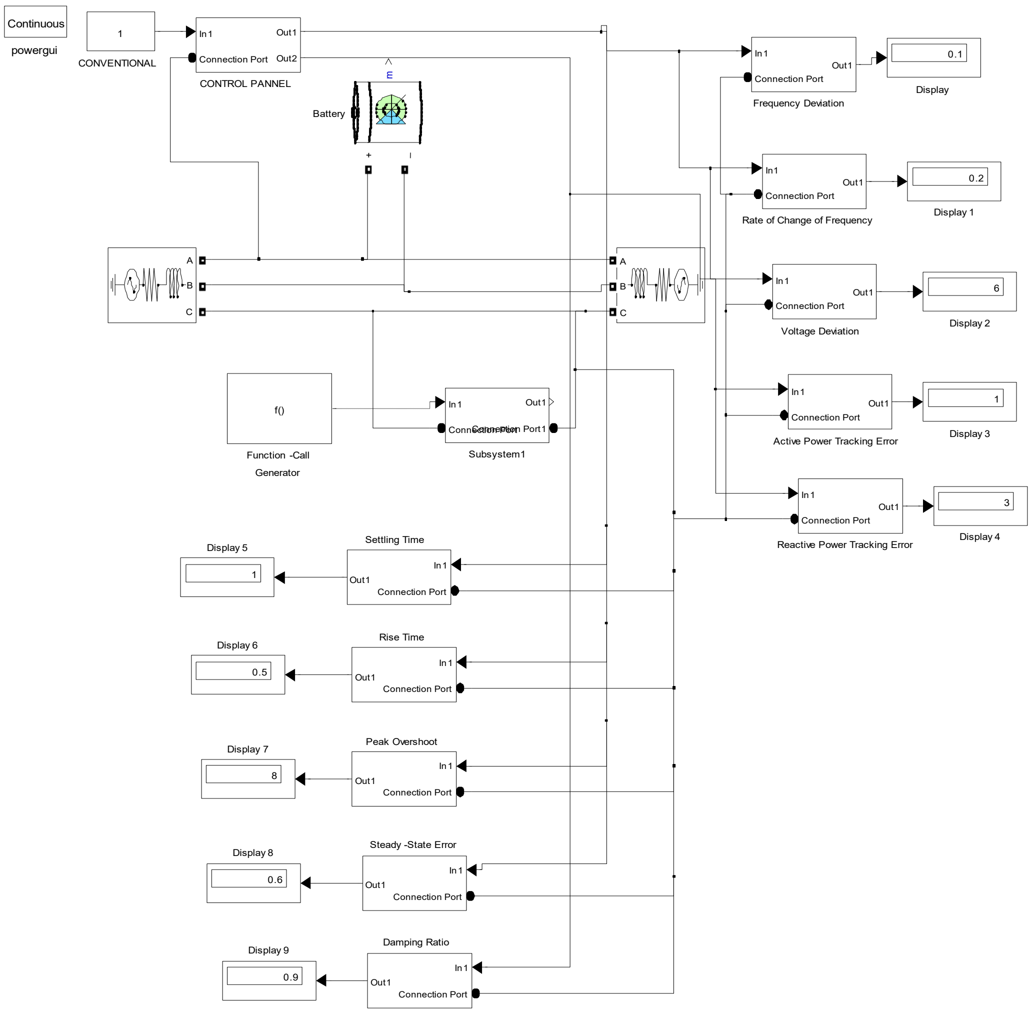

Fig 1 designed conventional SIMULINK model for virtual synchronous generator control

This was fully detailed in figures 7 and 8

To train ANN in the causes of poor virtual synchronous generator control

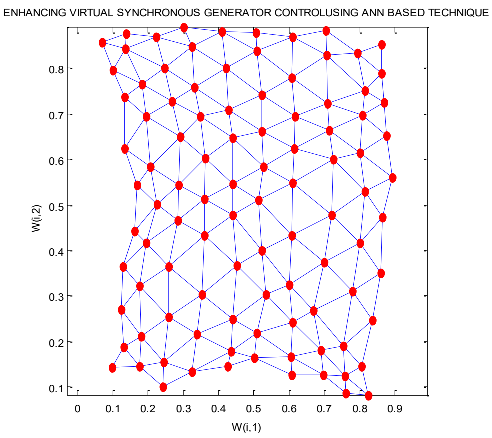

Fig 2 trained ANN in the causes of poor virtual synchronous generator control

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In this case ANN was trained ten times in the ten Performance Metric that caused poor virtual synchronous generator control 10 x 10 = 100 to give hundred neurons that looked like human brain.

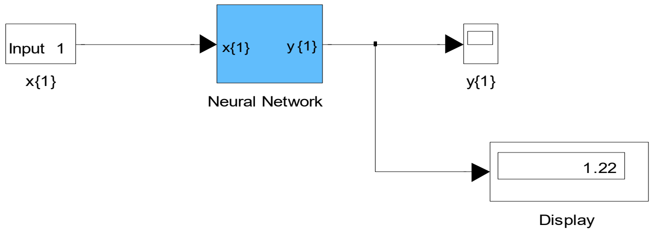

Fig 3 result obtained after the training ANN ten times in the ten Performance Metric that caused poor virtual synchronous generator control

On the other hand, if ANN was trained once in the ten Performance Metric that caused poor virtual synchronous generator control 1 x 10 = 10 to give ten neurons that looked like human brain as indicated in fig 4

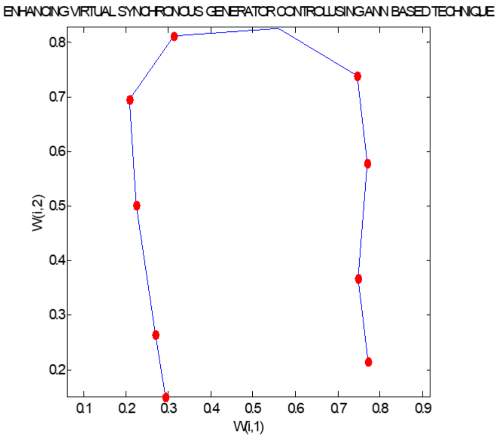

Fig 4 trained ANN in the causes of poor virtual synchronous generator control

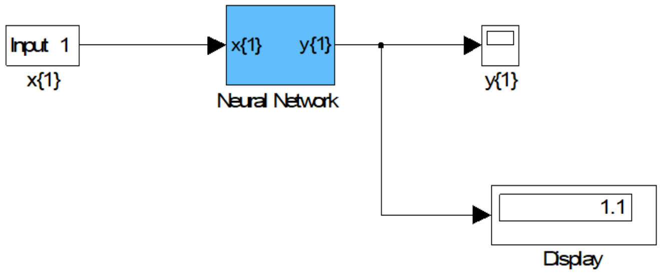

Fig 5 result obtained after the training ANN once in the ten Performance Metric that caused poor virtual synchronous generator control

This showed that when ANN was trained ten times it gave a better result when compared with when it was trained once. With these results obtained, it indicated that when ANN was trained ten times gave better result than when it was trained once.

To develop an algorithm that will implement the process

1.Characterize and establish the causes of poor virtual synchronous generator control

2. Identify Frequency Deviation that did not attain threshold.

3. Identify Rate of Change of Frequency that did not attain threshold

4.IdentifyVoltage Deviation that did not attain threshold

5. Identify Active Power Tracking Error that did not attain threshold

6.IdentifyReactive Power Tracking Error that did not attain threshold

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7.IdentifySettling Time that did not attain threshold

8.IdentifyRise Time that did not attain threshold

9.IdentifyPeak Overshoot that did not attain threshold

10.Identify Steady-State Error that did not attain threshold

11.IdentifyDamping Ratio that did not attain threshold

12.Design a conventional SIMULINK model for virtual synchronous generator control and integrate 2 through 12.

13.Train ANN in the causes of poor virtual synchronous generator control

14. Integrate 13 into 12

15.did the causes of poor virtual synchronous generator control reduce and attain threshold when i3 was integrated into12?

16.IF NO go to 14

17. IF YES go to 18

18.Enhanced virtual synchronous generator control

19.Stop.

20.End

To design a SIMULINK model for enhancing virtual synchronous generator control using ANN based technique

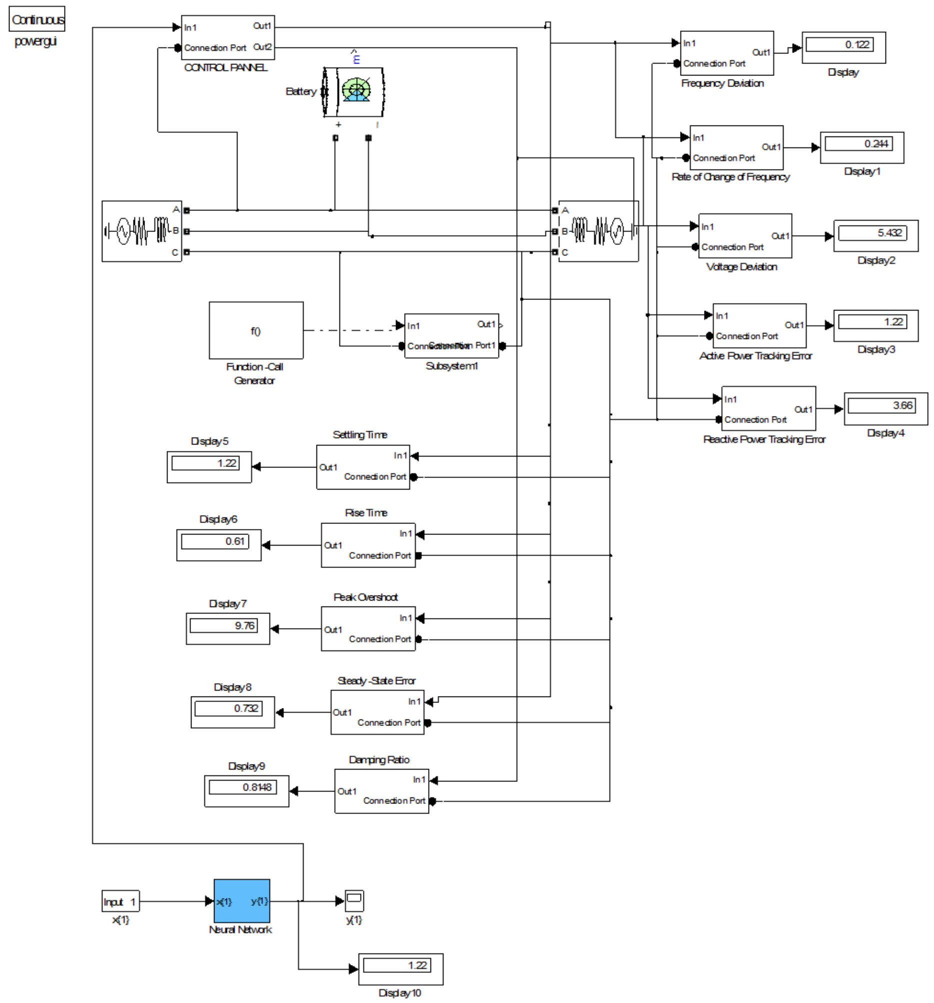

Fig 6 designed a SIMULINK model for enhancing virtual synchronous generator control using ANN based technique

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The results obtained were as shown in figures 7 and 8

To validate and justify the percentage improvement in the reduction of the causes of poor virtual synchronous generator control with and without an ANN based technique

To find percentage improvement in frequency deviation that causes poor virtual synchronous generator control with an ANN based technique

Conventional frequency deviation =0.18 Hz

ANN based technique frequency deviation =0.22 Hz

%improvement in frequency deviation that causes poor virtual synchronous generator control with an ANN based technique =

$$\frac{\text{ANN based technique frequency deviation - Conventional frequency deviation}}{\text{Conventional frequency deviation}} \times \frac{100\%}{1}$$

%improvement in frequency deviation that causes poor virtual synchronous generator control with an ANN based technique =

$$\frac{0.22\text{ Hz} - 0.18\text{ Hz}}{0.18\text{ Hz}} \times \frac{100\%}{1}$$

%improvement in frequency deviation that causes poor virtual synchronous generator control with an ANN based technique = 4%

To find percentage improvement in Voltage Deviation that causes poor virtual synchronous generator control with an ANN based technique

Conventional Voltage Deviation =6%

ANN based technique Voltage Deviation=5%

%improvement in Voltage Deviation that causes poor virtual synchronous generator control with an ANN based technique =

Conventional Voltage Deviation - ANN based technique Voltage Deviation

%improvement in Voltage Deviation that causes poor virtual synchronous generator control with an ANN based technique =6% - 5%

%improvement in frequency deviation that causes poor virtual synchronous generator control with an ANN based technique = 1%

RESULTS AND DISCUSSION

Table 2 comparison of conventional and ANN based technique frequency deviation that causes poor virtual synchronous generator control

Time (days)	Conventional frequency deviation that causes poor virtual synchronous generator control (Hz)	ANN based technique frequency deviation that causes poor virtual synchronous generator control (Hz)
1	0.18	.0.22

2	0.18	.0.22
3	0.18	.0.22
4	0.18	.0.22

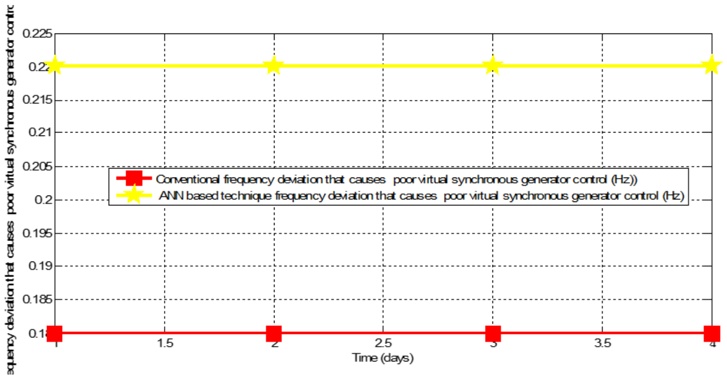

Fig 7 comparison of conventional and ANN based technique frequency deviation that causes poor virtual synchronous generator control

The conventional frequency deviation that causes poor virtual synchronous generator control was 0.18 Hz. because it could not attain the threshold of 0.2 Hz through 0.5 Hz. Meanwhile, when an ANN based technique was integrated into the system, it automatically increased by attaining the threshold 0.22Hz.

Table 3 comparison of conventional and ANN based technique voltage deviation that causes poor virtual synchronous generator control

Time (days)	Conventional voltage deviation that causes poor virtual synchronous generator control (%)	ANN based technique voltage deviation that causes poor virtual synchronous generator control (%)
1	6	5
2	6	5
3	6	5
4	6	5

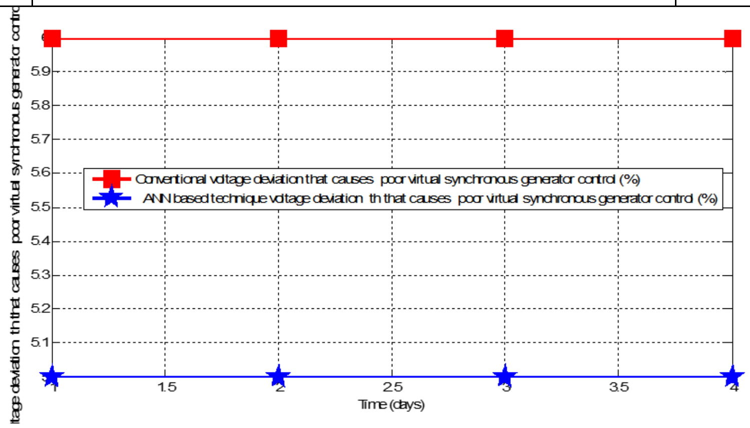

Fig 8 comparison of conventional and ANN based technique voltage deviation that causes poor virtual synchronous generator control

The conventional voltage deviation that causes poor virtual synchronous generator control was6%. Meanwhile when an ANN based technique was integrated into the system, it spontaneously reduced to 5 %. Finally, with these results obtained, the percentage enhancement in virtual synchronous generator control when an ANN based technique was integrated into the system was 1%.

CONCLUSION

The persistent power failure in the society and country generally this present time, that had crippled business activities was overcame by introducing enhancing virtual synchronous generator control using ANN based technique. to perfectly achieve this, it was done in this approach ,virtual synchronous generator control was characterized and the causes of poor virtual synchronous generator control were established, conventional SIMULINK model for virtual synchronous generator control was designed and ANN was trained in thecauses of poor virtual synchronous generator control. however, an algorithm that will implement the process was developed, a SIMULINK model for enhancing virtual synchronous generator control using ANN based technique was designed and the results obtained were validated and justified. The results obtained werethe conventional frequency deviation that causes poor virtual synchronous generator control was 0.18Hz. On the other hand, when an ANN based technique was integrated into the system, it instantly became0. 22Hz thereby meeting the threshold andthe conventional voltage deviation that causes poor virtual synchronous generator control was6%. Meanwhile when an ANN based technique was integrated into the system, it spontaneously reduced to 5 %. Finally, with these results obtained, the percentage enhancement in virtual synchronous generator control when an ANN based technique was integrated into the system was 1%.

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