

# Voltage Stability Improvement of Standalone SEIG Based Wind Plant Using Fuzzy Logic Controlled SVC

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## ARTICLE INFO

## ABSTRACT

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Self Excited Induction Generator (SEIG) is a major part of stand-alone wind vitality frameworks, are well known in later times among farther ranges. This situation occurs because these types of generators increasingly depend on much external intervention for reactive power control in isolated systems. This article focuses to analyse arranged applications of a static VAR compensator (SVC) for voltage control headway in division list SEIG based wind control systems. The standalone wind power plant has been developed along with the SEIG and fuzzy logic-based control of SVC. The simulations have been carried out without SVC, with open loop control of SVC, closed loop control of SVC and finally with Fuzzy based control of SVC. The developed standalone system simulations have been carried out for all resistive and inductive load scenarios with a constant power factor and obtain the data to sketch the power voltage (pv) curves of the system. The pv curves have been drawn for both resistive and inductive loads in all cases viz. open loop control, closed loop control as well as fuzzy logic-based control of SVC. The analysis on voltage stability of standalone wind plant has been done with all cases with both R and RL loads.

**Keywords:** SEIG, Wind Energy, Voltage Stability, SVC, Reactive Power Compensation, Standalone Systems.

## INTRODUCTION

The wind energy resource is being accorded greater importance as the worldwide demand for clean energy continues to rise. Especially, free wind imperativeness frameworks are rapidly picking up interested as a potential course of activity to supply control in provincial and confined ranges without get to the schedule control lattice. The self-excited induction generator (SEIG) is one imperative innovation among the Western generator sorts that discover application in these frameworks, which has ended up favourable primarily due to its lower taken a toll, vigorous plan, and relative ease of support.

Nevertheless, despite their seeming advantages, SEIGs provide operational difficulties, especially in standalone applications. The primary cause of the terminal voltage instability is the external reactive power need for the generator's excitation. Meanwhile, the change in wind speed or demand can worsen the voltage instability and eventually drift into poor power quality and voltage regulation. For the sake of the undisturbed steady-state operation of the stand-alone wind energy systems, these problems have to be tackled with.

Normally, voltage instability is corrected through reactive compensation methods. Being one of the most utilized and active technologies, the Static VAR Compensator (SVC) stands out. In dynamic conditions, it can improve terminal voltage and system performance by instantaneously changing its reactive power through reactive current injection or absorption.

Analysing how SVC technology can improve voltage stability in standalone SEIG-based wind energy systems is the aim of this article. This involves modelling and simulation of the system under various loading conditions and wind speed scenarios in MATLAB/ Simulink and evaluation of the performance of the developed model. According to the findings, the SVC contributes to the stabilization of the SEIG's terminal voltage, which raises the performance potential of independent wind power systems and increases their dependability and efficiency.

### WIND POWER PLANT

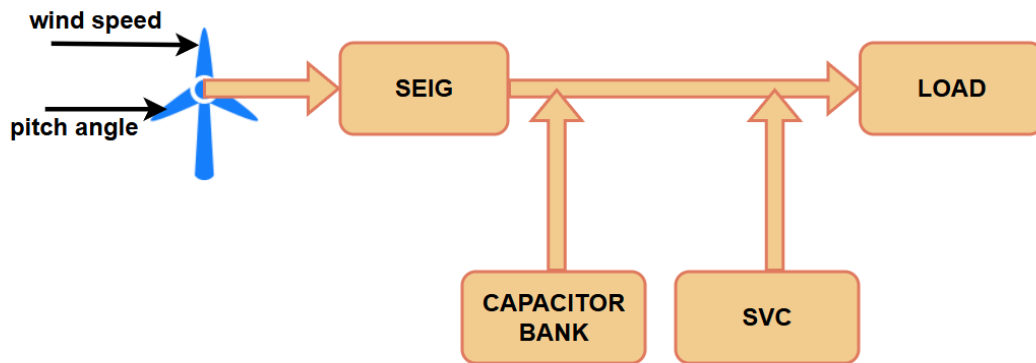
A wind power plant, referred to as wind energy conversion system (WECS), is a renewable energy facility which converts the kinetic energy from moving air into electrical energy. It speaks to a clean, maintainable, and generally cheap elective to fossil fills making it a favoured component of cutting-edge vitality frameworks. Fig.1 shows the block diagram of wind energy system. Wind control plants may work in either grid-connected mode or in stand-alone (off-grid) mode; this article analyses stand-alone frameworks essentially, which can be especially valuable in blocked off ranges [1] to [2] and [4] to [6].

$$P_w = \frac{1}{2} C_p(\lambda, \beta) \rho A V^3 \quad (1)$$

$$C_p = 0.22 \left( \frac{116}{x} - 0.4\beta - 50 \right) e^{-\frac{12.5}{x}} \quad (2)$$

$$\frac{1}{x} = \frac{1}{\lambda - 0.008\beta} - \frac{0.035}{(1+\beta)^3} \quad (3)$$

$$\lambda = \frac{wR}{v} \quad (4)$$



**Figure 1.** Wind power plant with SEIG with SVC

### SELF-EXCITED INDUCTION GENERATOR

A Self-Excited Induction Generator (SEIG) is an induction machine that generates electricity in stand-alone mode, without connection to the grid. SEIGs are utilized as generators for small-scale renewable vitality (e.g. wind or micro-hydro) applications due to their simplicity of design, low cost and their robustness as a machine. SEIGs differ from induction generators typically found in the literature which connect to the grid to provide the reactive power necessary for the induction machine function. In an SEIG, the generator draws excitation current from a capacitor bank connected across the stator terminals. As the rotor is driven above synchronous speed by a mechanical prime mover, with sufficient capacitance across the stator terminals, the generator will self-excite based on residual

magnetism in the core. This process results in voltage buildup, and eventually a steady state established whereby capacitive reactive power balances the magnetizing of the machine. Fig.2 illustrates the self-excited induction generator with excitation capacitor, SVC, and Load. The modelling equations of Induction Machine as described by the stator and rotor side voltage and flux linkage equations as below [1] and [6] to [12].

Stator side equations

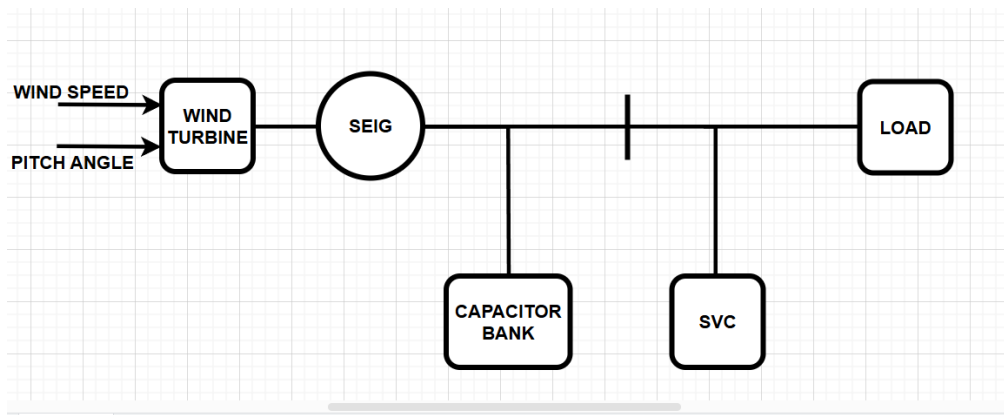
$$V_{abcs}^a = r_s(i_{abcs}^a) + \frac{d\lambda_{abcs}^a}{dt} \quad (5)$$

$$\lambda_{abcs}^a = (L_s + M)(i_{abcs}^a) + L_{sr}(i_{abcr}^a) \quad (6)$$

Rotor side equations

$$0 = r_r(i_{abcr}^a) + \frac{d\lambda_{abcr}^a}{dt} \quad (7)$$

$$\lambda_{abcs}^a = (L_r + M)(i_{abcs}^a) + L_{sr}(i_{abcr}^a) \quad (8)$$



**Figure 2.** Self excited induction generator with capacitor bank, SVC, and Load

### STATIC VAR COMPENSATOR

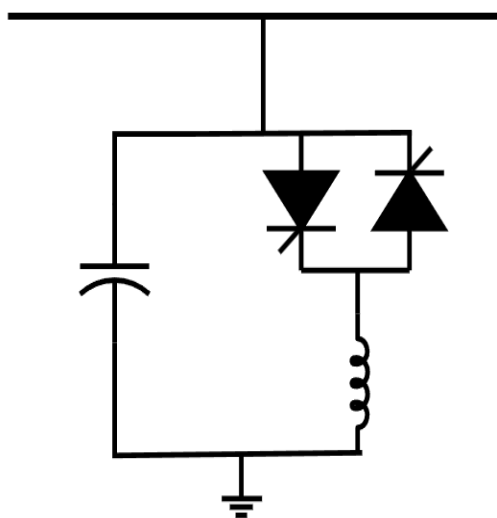
A Static VAR Compensator (SVC) is a power electronics device designed for dynamic reactive power compensation and voltage regulation in power systems. This is a member of a family of flexible alternating current systems (FACTS) that are typically used for grids and independent applications for voltage stabilization and improved performance quality. In a self-excited induction generator scheme for wind energy systems, SVCs are valuable in providing or absorbing reactive power based on need and, in turn, maintaining constant terminal voltage with varying wind speeds and loads. Fig.3 SVCs adjust reactive performance by steering the fire angle of the thyristors with devices such as thyristor control reactors (TCRs) and thyristor switched condensate (TSCs) that allow for quick and accurate reactive power. The modelling equations of SVC as described by equations as below [3] and [13].

$$Q_{svc} = V^2 \left( \frac{1}{x_c} - \frac{1}{x_L(\alpha)} \right) \quad (9)$$

$$B_{svc} = B_c + B_L(\alpha) \quad (10)$$

$$B_L(\alpha) = \frac{1}{\omega L} \left( 1 - \frac{2}{\pi} \alpha - \frac{1}{\pi} \sin 2\alpha \right) \quad (11)$$

$$I_L(\alpha) = \frac{V}{\omega L} \left( 1 - \frac{2}{\pi} \alpha - \frac{1}{\pi} \sin 2\alpha \right) \quad (12)$$

**Figure 3.** Static Var Compensator (SVC)

### FUZZY LOGIC CONTROLLER

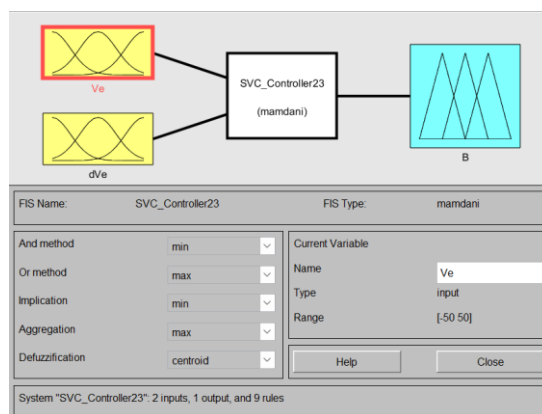
The Fuzzy Logic Controller (FLC) is a progressive control approach with intelligent ability to regulate the effect of a static VAR compensator (SVC) in a power supply system. Despite various wind currents and load conditions, it can maintain independent windshield voltage stability based on SEIG.

Two inputs are processed by the FLC, namely, the voltage error (the difference of what should be reference or actual voltage) and change in voltage error. Based on a defined set of fuzzy rules and linguistic variables, then, it is able to generate a control signal, well adapted to the required action scenario to modify that SVC firing angle. In this way, the reactive power flow will be manipulated dynamically and also improve voltage regulation [11] and [12].

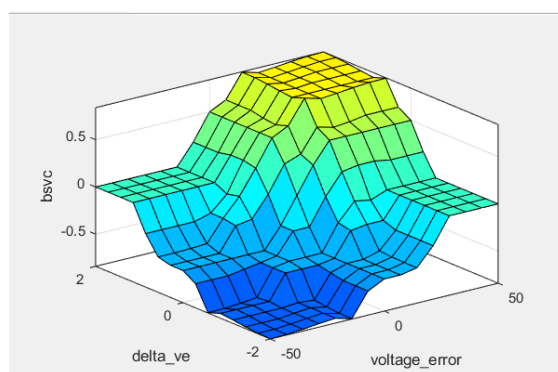
Fuzzy logic does not require the exact system model that traditional controllers require to operate nonlinear and uncertain systems. Therefore, high speed, self-adaptive and robust controllers have been developed to improve the performance of independent wind power systems [12].

**Table 1:** Fuzzy rules for fuzzy logic controller with SVC

| VE\ΔVE | NB | NM | ZE | PM | PB |
|--------|----|----|----|----|----|
| NB     | NB | NB | NM | NM | ZE |
| NM     | NB | NM | NM | ZE | ZE |
| ZE     | NM | NM | ZE | PM | PM |
| PM     | NM | ZE | PM | PB | PB |
| PB     | ZE | ZE | PM | PB | PB |



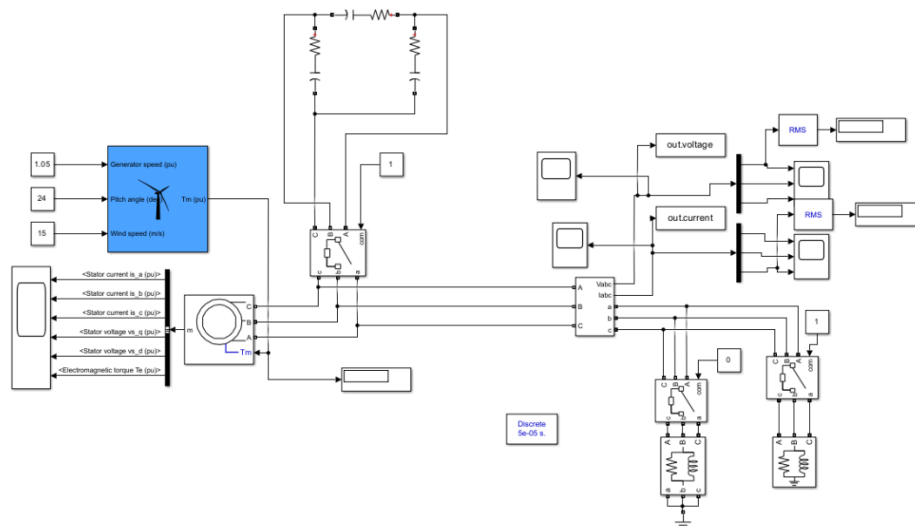
**Figure 4.** Triangular input and output membership functions of fuzzy controller



**Figure 5.** Fuzzy 3-D rules surface

### SIMULATION AND RESULTS

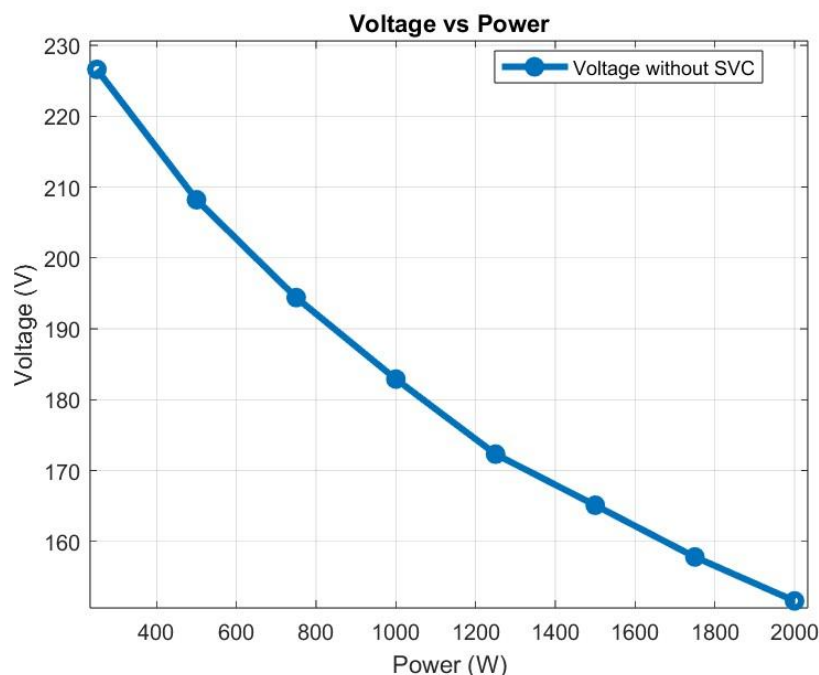
The standalone SEIG-based wind energy system was examined to study the performance of the SVC and various control strategies under four specific operating conditions for evaluating the influence of SVC on these conditions. Fig.6 shows the Simulink model of system without SVC. Here, it was established that the system was operating without compensation. Fig.7 and Fig.8 depicts PV curves for R and RL load without SVC. From Fig.7 and Fig.8 It was found that this terminal voltage fluctuated widely and was primarily dependent on changes in wind speed and load demand. Without reactive power support, the SEIG was unable to maintain voltage stability, resulting in poor voltage regulation as well as unreliable system performance.

**Figure 6.** Simulink model without SVC**Table 2:** Power and voltage with varying R load without SVC

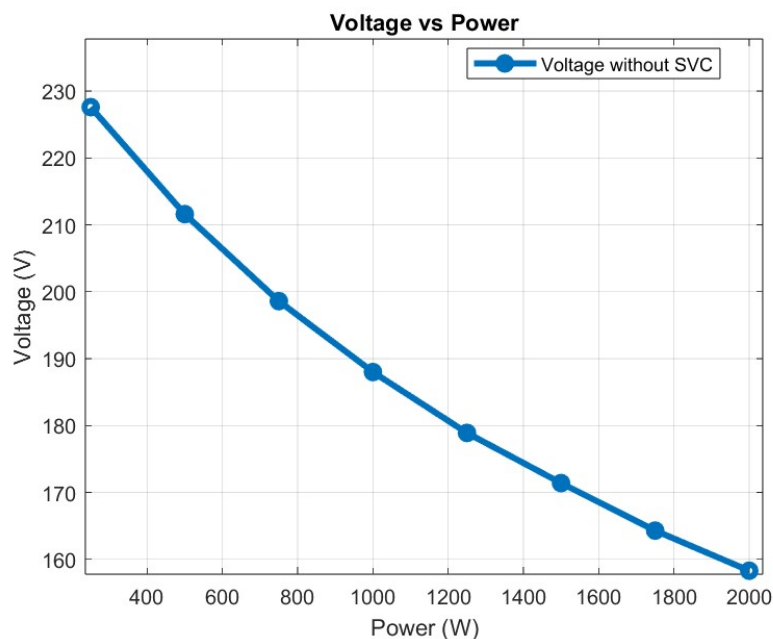
| Parameter    | R load 1 | R load 2 | R load 3 | R load 4 | R load 5 | R load 6 | R load 7 | R load 8 |
|--------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Active Power | 250      | 500      | 750      | 1000     | 1250     | 1500     | 1750     | 2000     |
| Voltage      | 226.27   | 208.24   | 194.45   | 182.92   | 172.31   | 165.109  | 157.89   | 151.60   |

**Table 3:** Power and voltage with varying RL load without SVC

| Parameter      | RL load 1 | RL load 2 | RL load 3 | RL load 4 | RL load 5 | RL load 6 | RL load 7 | RL Load 8 |
|----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Active power   | 250       | 500       | 750       | 1000      | 1250      | 1500      | 1750      | 2000      |
| Reactive power | 187.5     | 375       | 562.5     | 750       | 973.5     | 1125      | 1312.5    | 1500      |
| Voltage        | 227.68    | 211.68    | 198.69    | 188.03    | 178.93    | 171.40    | 164.33    | 158.32    |

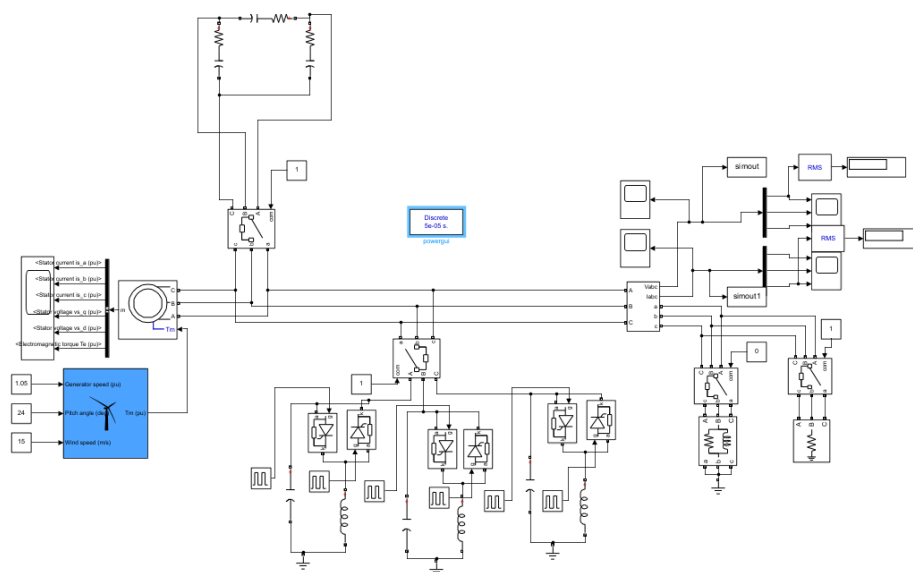


**Figure 7.** Power vs voltage curve for R load without SVC



**Figure 8.** Power vs voltage curve for RL load without SVC

Fig.9 shows the Simulink model of system with SVC with open loop control. In the second operating environment, the system was integrated with an open-loop SVC that provided a constant amount of reactive power. Fig.10 and Fig.11 depicts the PV curves for R and RL load with SVC with open loop control. Although this situation was relatively better than that under the uncompensated case, it did not possess any attributes to modifying the configuration as system conditions would dynamically change. So, voltage regulation was still not sufficient under the overloading or sudden disturbance conditions.

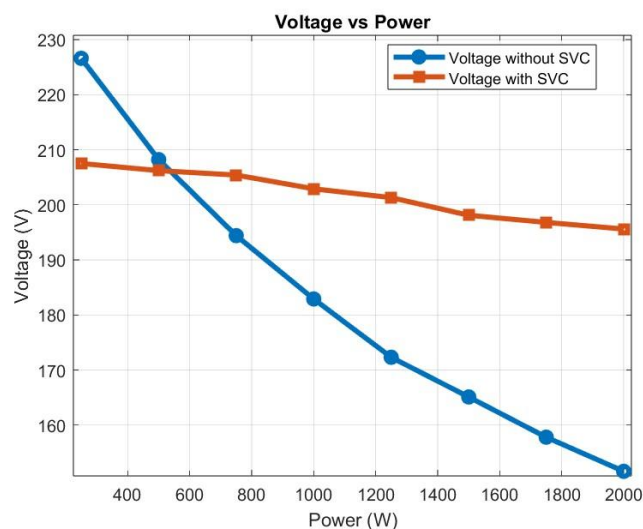
**Figure 9.** Simulink model with SVC with open loop control**Table 4:** Power and voltage with varying R load with SVC with open loop control

| Parameter    | R load 1 | R load 2 | R load 3 | R load 4 | R load 5 | R load 6 | R load 7 | R load 8 |
|--------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Active Power | 250      | 500      | 750      | 1000     | 1250     | 1500     | 1750     | 2000     |
| Voltage      | 207.04   | 206.24   | 205.45   | 202.92   | 201.31   | 198.10   | 196.89   | 195.60   |

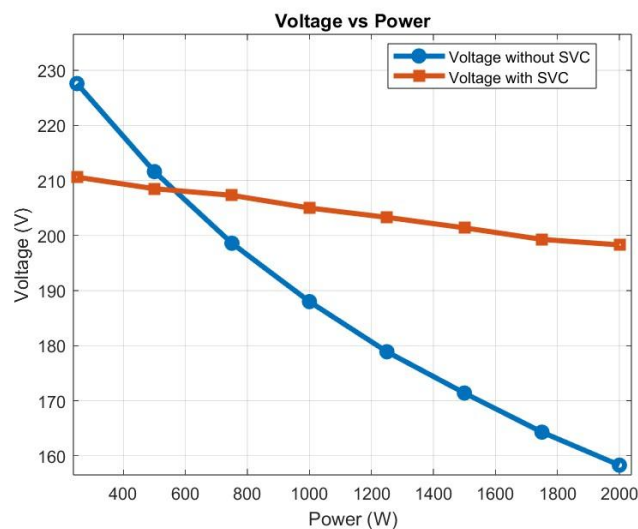
**Table 5:** Power and voltage with varying RL load with SVC Open Loop Control

| Parameter      | RL load 1 | RL load 2 | RL load 3 | RL load 4 | RL load 5 | RL load 6 | RL load 7 | RL Load 8 |
|----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Active power   | 250       | 500       | 750       | 1000      | 1250      | 1500      | 1750      | 2000      |
| Reactive power | 187.5     | 375       | 562.5     | 750       | 973.5     | 1125      | 1312.5    | 1500      |
| Voltage        | 210.68    | 208.58    | 207.39    | 205.03    | 203.36    | 201.40    | 199.33    | 198.32    |



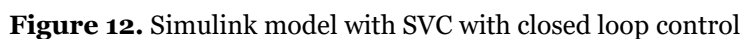


**Figure 10.** Power vs voltage curve for R load with SVC with open loop control



**Figure 11.** Power vs voltage curve for RL load with SVC with open loop control

The working of the closed-loop SVC was established in its third case study, having a typical feedback controller. Fig.12 shows Simulink model of system with SVC with closed loop control. The controller was able to apply reactive power injection with real-time voltage measurements. Fig.13 shows the closed loop controller of SVC. The effectiveness of the closed-loop arrangement improved as far as the voltage stability and recovery time was concerned, after a disturbance. Fig.14 and Fig.15 shows PV curves for R and RL load with SVC with closed loop control. However, such performance had a direct link to the tuning of the controller and was relatively poor with respect to handling of nonlinear or uncertain conditions.

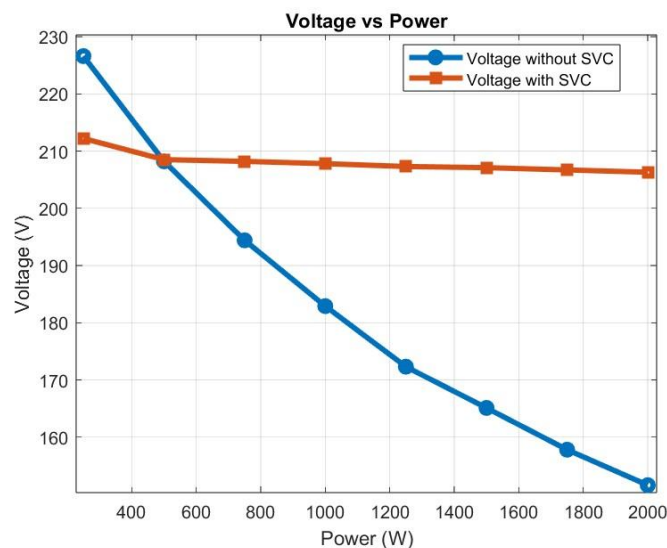


**Table 6:** Power and voltage with varying R load with SVC with closed loop control

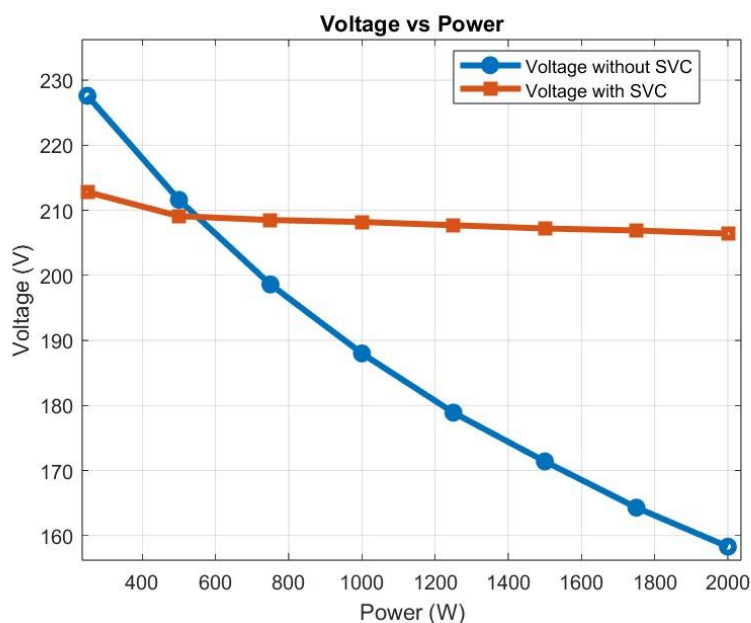
**Table 7:** Power and voltage with varying RL load with SVC with closed loop control

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|                |       |       |       |       |       |       |        |       |
|----------------|-------|-------|-------|-------|-------|-------|--------|-------|
| Active power   | 250   | 500   | 750   | 1000  | 1250  | 1500  | 1750   | 2000  |
| Reactive power | 187.5 | 375   | 562.5 | 750   | 973.5 | 1125  | 1312.5 | 1500  |
| Voltage        | 212.8 | 209.1 | 208.5 | 208.2 | 207.7 | 207.2 | 206.9  | 206.4 |



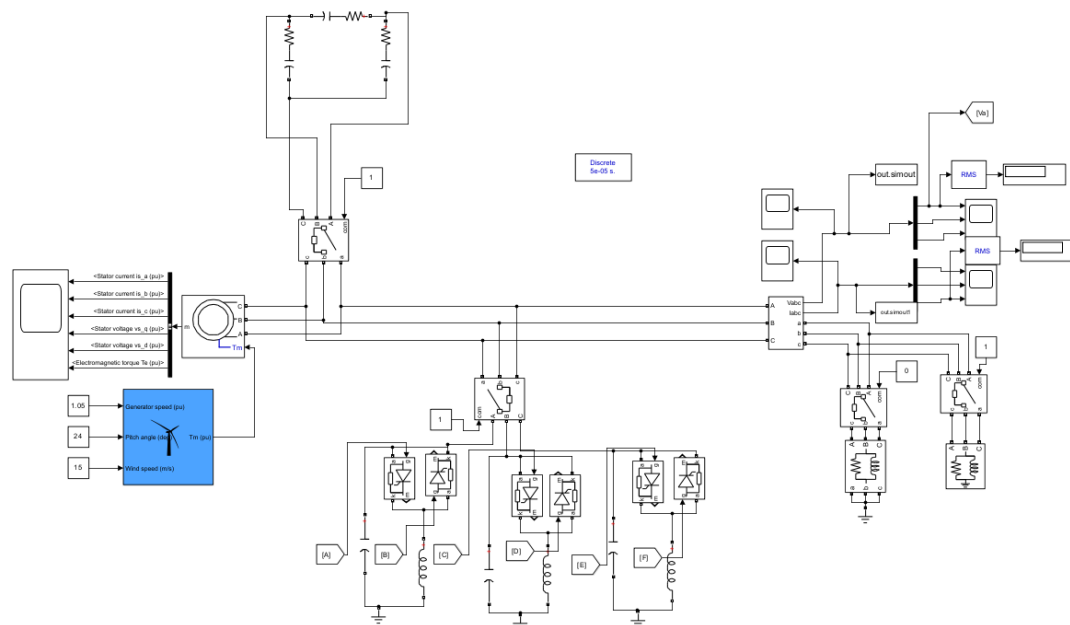
**Figure 14.** Power vs voltage curve for R load with SVC with closed loop control



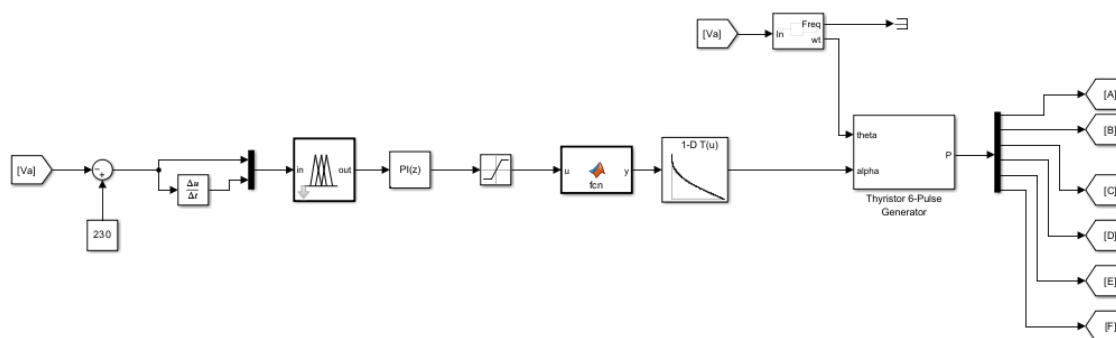
**Figure 15.** Power vs voltage curve for RL load with SVC with closed loop

Fig.16 shows the Simulink model of system with SVC with fuzzy logic control. Finally, in the fourth case, fuzzy logic-controlled SVC was put into application. Fig.17 shows the fuzzy logic controller for SVC. The intelligent controller had the processing of voltage error and rate of its change to determine the control action. Fig.18 and Fig.19 depicts PV curves of R and RL load with SVC with fuzzy logic control. Performance of the fuzzy-based SVC system was outstanding in keeping the profile steady with regard to fluctuating wind speed and load condition. It gave rapid

dynamic response, minor deviation in voltages, and good adaptability to system nonlinearity, thus being the most effective control method from the tested scenarios.



**Figure 16.** Simulink model with SVC with fuzzy logic controller



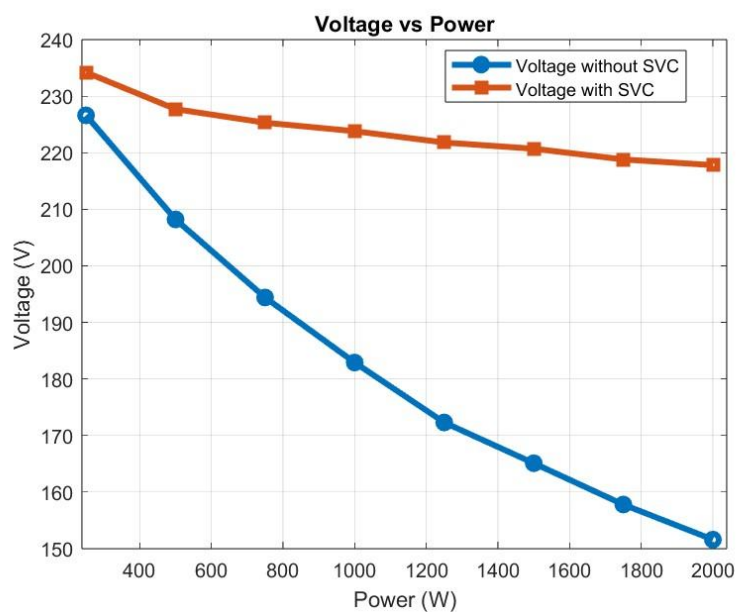
**Figure 17.** Fuzzy logic control for SVC

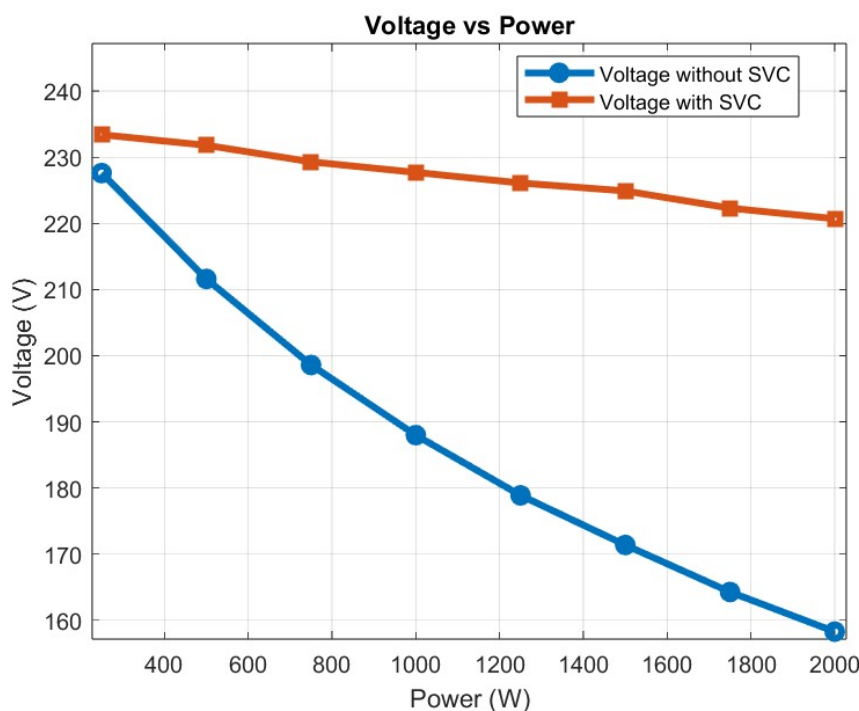
**Table 8:** Power and voltage with varying R load with SVC with fuzzy logic control

| Parameter    | R load 1 | R load 2 | R load 3 | R load 4 | R load 5 | R load 6 | R load 7 | R load 8 |
|--------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Active Power | 250      | 500      | 750      | 1000     | 1250     | 1500     | 1750     | 2000     |
| Voltage      | 234.2    | 227.7    | 225.3    | 223.8    | 221.8    | 220.7    | 218.8    | 217.5    |

**Table 9:** Power and voltage with varying RL load with SVC with fuzzy logic control

| Parameter      | RL load 1 | RL load 2 | RL load 3 | RL load 4 | RL load 5 | RL load 6 | RL load 7 | RL Load 8 |
|----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Active power   | 250       | 500       | 750       | 1000      | 1250      | 1500      | 1750      | 2000      |
| Reactive power | 187.5     | 375       | 562.5     | 750       | 973.5     | 1125      | 1312.5    | 1500      |
| Voltage        | 233.4     | 231.8     | 229.3     | 227.7     | 226.1     | 224.9     | 222.3     | 220.7     |

**Figure 18.** Power vs voltage curve for R load with SVC with fuzzy logic controller



**Figure 19.** Power vs voltage curve for R load without SVC with fuzzy logic controller

The comparative analysis ultimately indicates that the incorporation of SVC with fuzzy logic controller is a brighter perspective in bringing about considerable improvement in voltage stability and a broader performance threshold of the systems as standalone SEIG-based wind power plants.

## CONCLUSIONS

This paper presents an analysis of improvements in voltage stability in an independent self-excitation induction generator (SEIG)-based wind energy system using a static VAR compensator (SVC). It was established that the inherent limitations of SEIG, where it relies on external reactive power for excitation, cause voltage instability during varying wind and load conditions. Therefore, it was inspected the system output under various operating conditions, including open-loop control, control with closed loop, and fuzzy logic control of SVC.

The simulation results indicate that the uncompensated system had very poor voltage regulation, especially during reactive load conditions. Open-loop compensation by SVC results in moderate improvement in system voltage stability under varying operating conditions but was rather inflexible to adapt to any dynamic situation. Further enhancement of voltage stability has been maintained by real-time feedback under closed-loop mode, although the performance still came short under nonlinear conditions. For optimal performance, fuzzy logic control was applied intelligently and adaptively in the management of the SVC. This approach has been successful in ensuring voltage stability, minimizing variation and improving the voltage stability of independent wind energy systems. In conclusion, SVC has proven to be a highly effective option for improving voltage stability in SEIG-based independent wind farms using the fuzzy logic controlled SVC.

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