

Review on the Electric Spring Connected to the Renewable Energy System to Minimize Harmonics and Voltage Profile Enhancement

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Abstract. The emerging smart grid technology known as Electric Spring (ES) has been employed previously to maintain voltage and power stability in renewable energy-based grids that are minimally regulated or self-contained. This study thoroughly investigated the foundational theories, modeling approaches, practical uses, and restrictions associated with Electric Springs by analyzing existing Scholarly works in this domain. Electric Springs implement a direct power control approach. solution for the next-generation single-phase Systems, addressing the limitations of current ES control methods. This solution aims to improve power management in microgrids, where integrating renewable energy sources (RESs) poses challenges due to the unpredictable power output. The challenge involves managing two aspects: the variable Power consumed by ES and the power fed into the grid. The suggested straightforward and accurate signal manipulation method, namely, ANN-based Electric Spring (ES), is set to be deployed. This technique can adeptly manage these aspects in both stable conditions and during transitions in Renewable Energy Sources (RES).

1 Introduction

Electric Springs (ESs) have emerged as a promising technology for managing distributed demand response, addressing voltage and frequency fluctuations in AC power systems, especially those heavily reliant on intermittent renewable energy sources. This research investigates the idea of Electric Springs as a recent addition to demand-side management (DSM) strategies, specifically designed to regulate local voltage within AC power grids at any point of common coupling (PCC). ES can be realized utilizing a half-bridge single-phase inverter equipped with an inductor-capacitor output filter to remove high-frequency pulse width modulation signals. The paper provides an overview of the underlying concept of Electric Springs, which includes the utilization of capacitors for voltage stabilization, provides valuable insights into the behaviour of ES. Moreover, it examines the fundamental principles guiding ES operation with batteries, detailing its eight potential operating modes and their importance in achieving line current regulation [1]-[4]. Integrating traditional PI

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and P controller techniques into this smart grid technology has presented challenges in terms of performance, necessitating a shift towards modern controllers such as fuzzy logic and neural networks. These advanced controllers aim to ensure smoother and more stable voltage control while minimizing Total Harmonic Distortion [5]-[8].

The main goal of this paper is to delineate the efficiency of Electric Spring in a range of beneficial applications. Subsequent chapters will explore the evolution and practical implementation of this technology in greater detail.

Hooke. This concept has metamorphosed into what we now recognize as "electric springs." Electric springs have demonstrated their effectiveness in regulating mains voltage, even in the face of fluctuations resulting from the sporadic character of renewable energy resources. The scientific foundation of Hooke's law, initially applied to mechanical springs, has been extended to formulate the concept of electric springs, with new scientific applications pertinent to contemporary society. The paper offers explanations on the scientific principles, diverse operating modes, and the limitations of electric springs [9] -[10]. The genesis of this innovative smart grid technology can be traced back to the scientific principles behind "Mechanical Springs" clarified by the 17th- century British physicist Robert.

Table 1 Examines various control approaches. The imminent energy crisis and escalating environmental worries mandate the extensive incorporation of renewable energy sources into our upcoming energy framework, be it through centralized power facilities or decentralized generators. Considering the intrinsically fluctuating characteristics of renewable energy sources, this envisaged overhaul of our power networks demands sophisticated control methods and the creation of a new field concentrated on efficient management tactics [1]-[17].

Key Discoveries Involving the Integration of Electric Springs with Renewable Energy Systems

Reference	Authors	Year	Objective	Algorithm	Test Systems
[1]	Parag Kanjiya, And Vinod Khadkika.	2013	Addressing Voltage Fluctuations	Control Algorithm for Electric Springs in 2-Bus Systems Using PI Control	Generator and Load bus.
[2]	Chi Kwan Lee et al.	2013	Minimizing Energy Storage Needs in Power Grids	Experimental Configuration for Power Grid Test Bed	POWER GRID System
[3]	Yan Shuo et al.	2014	Enhancing Power Factor	PWM Technique	Generator and Load bus.
[4]	Abdul Mannan Rauf	2015	Ensuring Voltage Stability in Distribution Grids	hunt Voltage Source Inverter (VSI)	Two Bus system
[5]	Xiao Luo et al.	2015	Voltage Control	STATCOM	Multi Bus system

[6]	Abdul Mannan Rauf et al.	2015	Stability of Voltage	Nine-Switch Converter Topology.	Multi Bus System
[7]	S. K. Panda et al.	2016	Boosting Voltage	Sinusoidal Pulse Width Modulation (SPWM)	Two bus system
[8]	Romika Sharma	2016	Variations in Line Voltage	Sinusoidal Pulse Width Modulation (SPWM) in Grid-Connected Systems	Grid Connected System
[9]	Heng Liu	2016	Quality of Power Supply	Pulse Width Modulation (PWM) Inverter in Islanded Systems	Islanded System
[10]	Eberhard Waffenschmidt et al.	2006	Compensation for Active and Reactive Power.	Unified Electric Spring Topology in Single-Machine Infinite Bus (SMIB) Systems	SMIB System
[11]	Qingsong Wanget al.	2016	Voltage Regulation	BiDirectional Phase-Shift Full-Bridge Converter (PSFBC) in 2-Bus Systems)	Two bus system
[12]	Esmail Keykha h et al.	2017	Controlling Voltage Fluctuations While Maintaining Electric Spring (ES) Efficiency	Full-Bridge Inverter	Two bus system
[13]	Kanakesh V.K et al.	2017	Frequency Characteristics	Sinusoidal Pulse Width Modulation (SPWM) in IEEE 2-Bus Systems	Two bus system
[14]	Yunlei Jiang et al.	2018	Power Regulation	PWM & SPWM	Two bus system
[15]	Heng Liu Et Al.	2020	Voltage Regulation	Three Angle Control Strategies	Three bus system
[16]	WEI Yi	2021	Fluctuations in Power Grid Current	Attributes of Rapid and	Two bus system

				Precise Voltage Regulation	
[17]	Xiaohu Wang	2022	Power Flow Direction in High Penetration Microgrid	Circuit Theory	Two bus system

Table 2 Describes the need for advanced smart grids driven by modern power electronics and the requirement for creative load management techniques to handle the fluctuations and unpredictability linked to renewable energy sources (RES). This method is viewed as a hopeful resolution to tackle these challenges and boost the overall efficiency and dependability of the power grid [19] - [28].

Key discoveries regarding Electric Springs' control over harmonics and voltage profiles

Reference	Authors	Year	Objective	Algorithm	Test Systems
[19]	Swagat Pati Et Al.	2022	Enhancing the flow of power, in Hybrid Isolated Systems	Electric Spring Topology Based on Nine-Switch Converter	Three bus system
[20]	Lohit Ranjan Lenka ;Et Al.	2022	Management of Power Control, Minimizing Disturbances	Series and Shunt Converters	Four bus system
[21]	Soumya Mohanty Et Al.	2022	Addressing Voltage Stabilization Challenges Arising from Load Variations	Slide Mode Controller (SMC)	Two bus system
[22]	Soumya Mohanty Et Al.	2022	Stabilizing Voltage	Strategy for Voltage Injection	Two bus system
[23]	Xiaohu Wang Et Al.	2022	Steadiness of the Line Voltage	Control Strategy with Fixed Angles	Two bus system
[24]	Hin Sang Lam Et Al.	2023	Managing Grid Voltage, Enhanced Voltage Stability Enhanced Voltage Stability	Improved Droop Voltage Control Method	Two bus system
[25]	Akash Agrawal	2023	Voltage Stability Redirecting Voltage Fluctuations to Non-Critical Loads Voltage Fluctuation Management in Non-Critical Loads	Fuzzy PI Controller	Three bus system

[26]	Xinyuan Chen Et Al.	2023	Managing Voltage Fluctuations in Non- Critical Loads Voltage Fluctuation Control in Non-Critical Loads	Particle Swarm Optimization (PSO)	Five Bus system
[27]	Jianhua Gong Et Al.	2023	Reducing Power Losses and Voltage Violations to a Minimum	Coordinated Control of Voltage and Reactive Power	Five Bus system
[28]	Darwin Alexis Quijano Rodezno et Al.	2023	Incorporating Renewable Generation into Power Systems and Voltage Regulation	Implementation of Fuzzy PI Controller	Three bus system

2 FORMULATION OF THE OBJECTIVE FUNCTION

In this analysis, Electric Springs are explored for enhancing voltage levels and decreasing harmonics. Additionally, various objective functions associated with Electric Springs are outlined below.

$$\text{Load voltage or output voltage } V_o = V_s - V_{es} \tag{1}$$

$$\text{Electric spring current } I = V_s - V_{es} / Z_o + V_s / Z_s \tag{2}$$

$$\text{Voltage stability } V_s = V_{es} + V_{ns} \tag{3}$$

$$\text{Voltage at point of common coupling} = V_{pcc}(t) = \sum_{N=1}^{\infty} V_n \sin(n\omega t + \theta) \tag{4}$$

$$\text{Active power control } P = VI \cos \phi \tag{5}$$

$$\text{Reactive Power } Q = VI \sin \phi \tag{6}$$

3 FUTURE RESEARCH OPPORTUNITIES

The current global energy scenario, characterized by the excessive use of fossil fuels and its adverse environmental effects, emphasizes the pressing need to promote renewable resources as a fundamental component of sustainable development. Incorporating sporadic renewable energy sources into the current power grid has not only expanded its capacity but has also posed challenges related to system stability.

This paper introduces a practical solution to tackle these challenges through an innovative technological concept known as "electric springs." Electric springs play a crucial role in enhancing system stability and enabling voltage regulation within the grid. By examining various analyses, control methods, and applications related to electric springs, this paper instils confidence in the technology's potential for further exploration and implementation in large-scale power distribution systems.

Moreover, the paper suggests that artificial neural networks (ANNs) could serve as a valuable tool for assessing the scope and potential of electric springs in the context of large-scale power distribution systems. ANNs possess the ability to model intricate and dynamic

systems, making them a promising avenue for optimizing the performance and integration of electric springs into the evolving energy landscape.

4 CONCLUSION

In this scenario, demand-side management, facilitated through the collaboration of the use of electric spring with a non-critical load is illustrated as an efficient approach. The intelligent load setup is engineered not only to fulfill its traditional role of stabilizing voltage but also to enhance power quality for critical loads.

To attain this dual capability, a fresh control approach for the electric spring is necessary is outlined in the above tables. These control techniques incorporate several resonant controllers in combination with a second-order generalized integrator, supplemented by the incorporation of a neural network controller. The suggested straightforward and accurate signal manipulation method, namely the Artificial Neural Network (ANN) based Electric Springs (ES), is set to be deployed. This technique can adeptly manage these aspects not only during stable operating conditions but also during transient states of non-conventional energy sources.

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