Effect of Electric Spring in minimizing voltage fluctuation in critical loads

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Abstract: This project describes the dynamic simulation approach for electric springs which is appropriate for voltage and frequency control .It is a new concept which provide system stability solutions. The use of Electric Spring is a new technology that has been used for the distributed voltage control. As there is a voltage fluctuation problems due to renewable energy sources, it is found to be an effective solution over the voltage fluctuations. To show the effectiveness of electric spring when installed in large number across the system, there is need of developing simple and accurate simulation models for these electric spring, which then can be incorporated in large scale power system simulation studies. Electrical spring addresses the main issues like reactive power management, voltage fluctuations and, power quality we will see Close similarity between the simulation and experimental results and it will give us the confidence to use this electric spring model for investigating the effectiveness of their standard operation when distributed in large number across a power system.

Index Terms – reactive power control,electric spring, critical load ,voltage fluctuation, stability

I. INTRODUCTION

In traditional power system the power generation is according to the load demand and usually the power demand is more than generation. To meet this local demand there are sources like wind, solar etc. But the problem with these sources is the voltage fluctuations due to change in environmental condition, if we are able to compensate these voltage fluctuations then we will get constant supply. The dynamic and changing nature of power generation in these sources makes the prediction of real time power generation difficult. Unpredictable and intermittent nature of renewable energy sources along with the expected high penetration in grids and microgrids may pose problems of voltage instability[8]. To overcome this issue a concept of Electric spring is introduced. Electric Springs has recently been proposed as simple way of distributed voltage control while simultaneously enabling effective demand-side management without any need of communication. This has been achieved through modulation of non-critical loads in response to the fluctuations in intermittent renewable energy sources (e.g. wind Electric springs (ES) injects a controllable voltage in series with the so called non-critical loads (which are less sensitive to voltage fluctuations) in order to regulate the voltage across the critical (voltage sensitive) loads. The power consumed by the noncritical load is modulated according to the input power resulting in frequency regulation. In this paper, an averaged simulation model for an electric spring is proposed to use in power system studies, Simulation results with the proposed averaged model are benchmarked against those obtained from the experiments To augment the existing research, an Electric Spring implemented through a full bridge pulse width modulation (PWM) based inverter is proposed and explained in Further, it has been tested on MATLAB Simulink platform and demonstrated how an ES can help in shaping reactive and active power and provide instantaneous voltage support.[1]

II. THEORETICAL FRAMEWORK

An electric spring, like a mechanical spring, is an electric device that can be used to:

1) Maintaining electric voltage;
2) ii) storing electric energy; and
3) iii) damping electric oscillations

The essential physical relationship of the electric spring is represented as, similar to equation-1.

$q = Cva$ inductive mode
$q = -Cva$ capacitive mode (1)

$q = \int ic\, dt$ (2)

Where q represents the electric charge stored in a capacitance capacitor, va is the electric potential difference across the capacitor, and is the current flowing into the capacitor. The charge stored in the capacitor can govern the dynamic voltage regulation (i.e., voltage boosting and decrease) operations of the electric spring, as shown in

Equation (1). Equation (2) indicates that the charge(q) control can be realized by using a controlled current source.

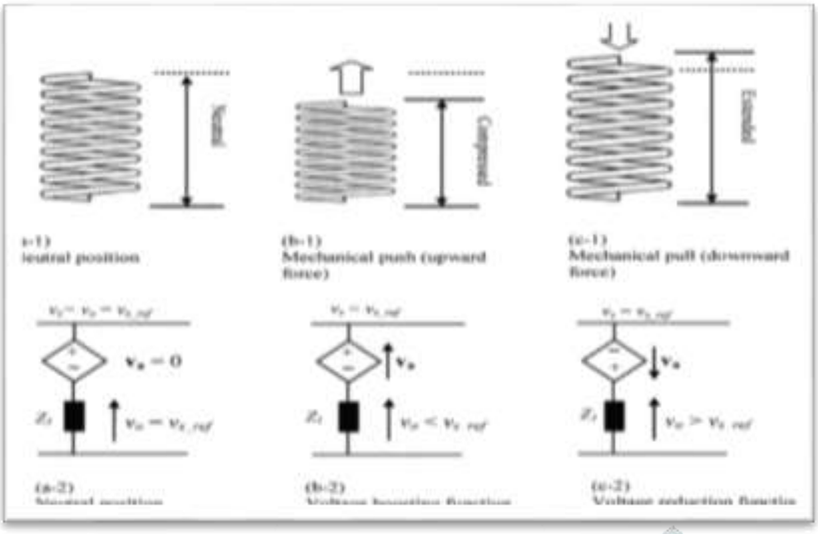

Fig:1 analogy of mechanical spring with electrical spring

As a result, an electrical spring are often thought of as a voltage source controlled by current. Figure 1 depicts an analogy between a mechanical spring and an electrical spring under three conditions. A dissipative electric load Z1 which is connected serial . an electrical spring's neutral state may be a reference voltage that the spring is meant to take care of . the electrical spring and Z1 are connected serial across the ac mains to stay the ac mains voltage Vs at its nominal reference level (e.g., 220 V), which is that the neutral state. an electrical spring can produce voltage boost within the same way that a mechanical spring can develop mechanical force in either direction when the displacement is adjusted from the neutral state., As shown in fig. 3.1.1, an electrical spring can perform voltage boosting and voltage decrease operations. the electrical al spring voltage are often produced in practise by manipulating the electric electric potential across a capacitor with a current source Ic dynamically.

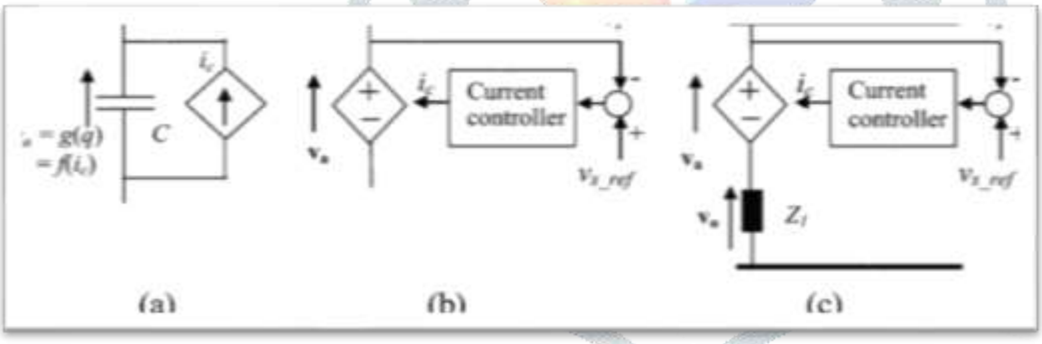

Fig. 2 (a) A regulated current source feeds an electric spring in the form of a capacitor.
(b) Electric spring schematic with input-voltage control.
(c) A dissipative load in series with an electric spring for energy storage,voltage support, and damping

The charge control in (2) allows for the generation of an electrical voltage in both directions, which may be wont to increase or lower the mains voltage during a power grid . the electrical spring's dynamic voltage support function is enabled by this control. The potential electric energy stored within the capacitor demonstrates the electrical spring's energy storage capability:

PE=1/2Cva2

As a result, the capacitor C functions because the electric spring's energy storage element. Because an electrical spring is meant to dampen electric oscillations, it must be connected serial with a dissipative electric load (such as a hot-water heater or a refrigerator, or a mixture of both) as shown in Fig 2. (c). The series-connected electric load Z1 are often utilized in two ways. to start with, it provides a way for dissipating electric energy for the aim of dampening. Second, the study will reveal that the voltage V0 across the electrical load Z1 and therefore the electric spring voltage Va can change during a unique way, causing the load power consumption Z1 to follow the fluctuation in renewable energy generation. the electrical spring's quality provides a completely unique thanks to support mains voltage in future power systems with intermittent renewable energy sources. the electrical spring operates like “voltage suspension,” almost like a mechanical suspension spring for a mechanical load, thanks to the series reference to the load Z1 (such as vehicle).

Control strategy and different operating modes of electric spring

The difference between the real ac mains voltage Vs and the reference mains voltage Vr is sent to a compensation controller, which could be a proportional-integral (PI) controller or a lead-lag compensator. The compensation controller's output serves as a control signal for the Pulse-Width-Modulated (PWM) generator. The phase information for the PWM generator, which creates the switching signals for the power semiconductor switches of a power inverter to generate a high-voltage sinusoidal PWM voltage waveform, is provided by a synchronisation networkThe power inverter's dc voltage is normally obtained from a capacitor that is charged through the inverter switches' anti-parallel diodes (like a diode rectifier with an output dc capacitor). A low-pass LC filter filters the PWM voltage supplied by the power inverter to provide an auxiliary sinusoidal voltage Va. It has been proved that when a smart load is operated in stand-alone mode, the critical section of the load maintains consistent voltage and power. When a smart load is linked to a power distribution system, the smart load's performance is influenced by the interaction between the system impedance and the smart load, as well as the voltage and power characteristics of the power supply. The electric springs can be dynamically operated in neutral, capacitive, or inductive mode with the goal of regulating the mains voltage due to the injection of both real and reactive electricity from distributed power sources in the future smart grid. The test is carried out to determine the various spring modes, which include

1. NEUTRAL MODE

When the spring is in neutral mode, it provides no compensation. Figure A. shows the waveforms of mains voltage (Vs), non-critical load voltage (Vo), electric spring voltage (Va), and electrical spring current (which is the same as the non-critical load current). The nominal value of the mains voltage Vsref is represented by the circle in the vector diagram (e.g., 220 V). At the mains frequency, the vectors are supposed to rotate in an anticlockwise manner (e.g., 50 Hz). Figure 3.2.2 (a) depicts the scenario when the electric spring is in the "neutral" position (Va=0).

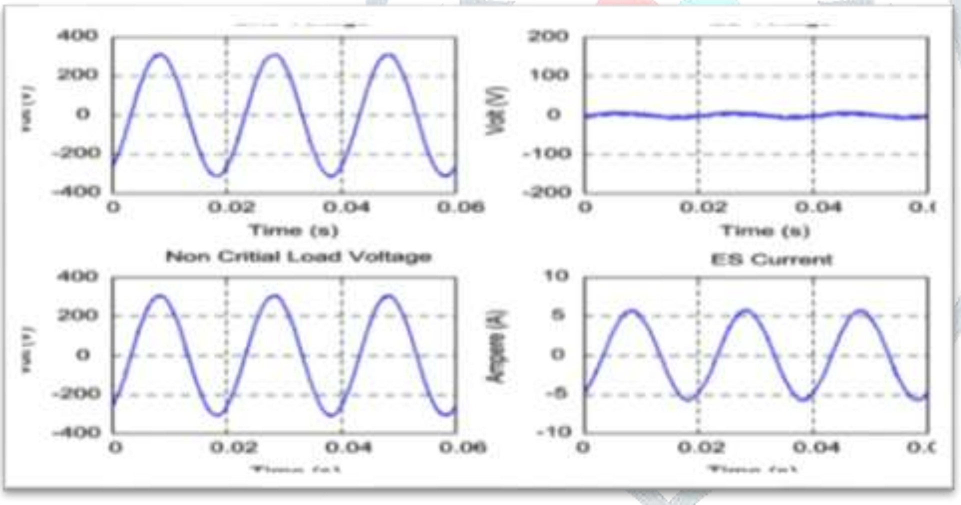

Fig: (a)Steady state electric spring waveforms under neutral mode.

2.CAPACITIVE MODE

Figure B depicts the waveforms when the spring is in capacitive mode. The electric spring current follows the electric spring voltage, as can be shown. The electric spring provides negative reactive power, and Vo is smaller than Vs. Vs will exceed Vsref if the generated power is more than the load demand, resulting in an over-voltage problem. The electric spring can provide "power boosting" function by working in the capacitive mode in order to adjust Vs at Vsref, as shown in Fig.

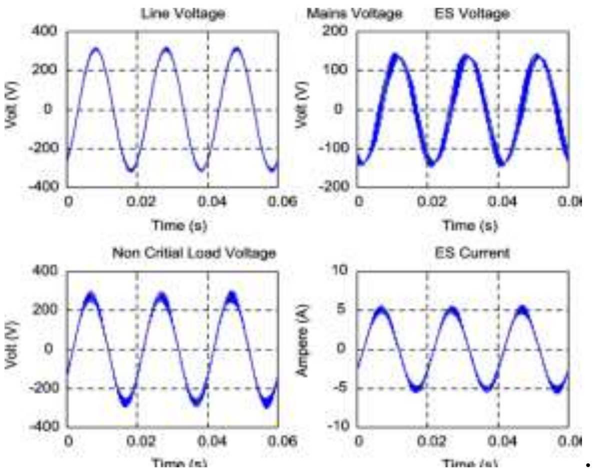

Fig: B Steady state electric spring waveform under capacitive mode

2. INDUCTIVE MODE

The spring then functions inductively, and the waveforms are depicted in figure 3.2.5. The electric spring current can be regulated to lag the electric spring voltage in this mode. To provide voltage support, an electric spring injects positive reactive power into the system. The condition depicted in Fig.3.2.2 (b) occurs when a power reduction in Z1 is required to retain Vs at Vsref. In order to offer the "power reduction" function under the inductive mode of the electric spring, is positive (making Vo less that Vsref).

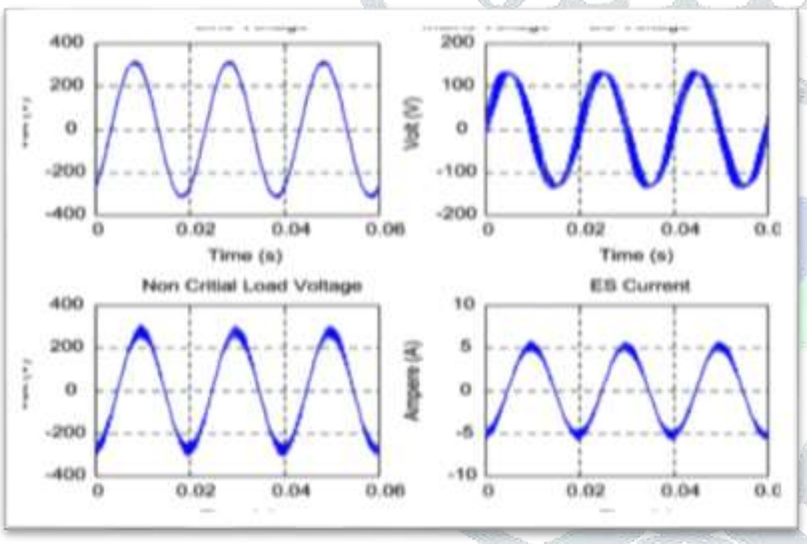

Fig: C Steady state electric spring waveform under inductive mode

Block diagram of electrical spring

Electric Spring (ES) may be a new smart grid technology which will provide electric active suspension functions for voltage and frequency stability during a distributed manner for future smart grid. supported Hooke's law, ES has been practically realized with power electronic circuits for improving both voltage and frequency stability in micro-grid hardware simulator. an equivalent functions for voltage and frequency stability have also been successfully evaluated during a simulation study for a medium sized power grid comprising several power generators. So far, three versions of ES are conceived. within the fundamental working principles and practical implementation of the primary generation of ES (i.e. ES-1) with capacitive storage are reported. By working under inductive and capacitive mode, ES-1 is capable of regulating the mains voltage to its par value within the presence of intermittent power injected into the facility grid. With input voltage control, ES can work with non-critical loads that have high tolerance of voltage fluctuation. samples of the non-critical loads are thermal loads like storage systems, electric hot-water heater systems, air-conditioning systems and a few public lighting systems.

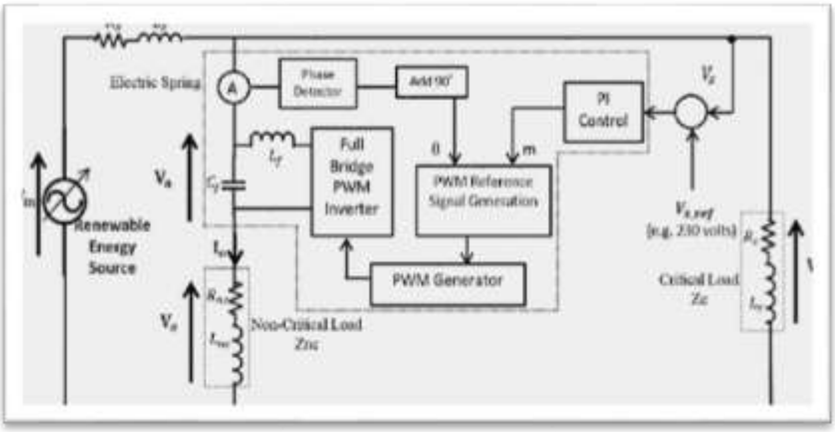

Fig:3 Realization of an Electric Spring in a Circuit with a control block diagram for a resistive-inductive load in an under-voltage state with variable input voltage for a resistive-inductive load in an under-voltage condition

System model

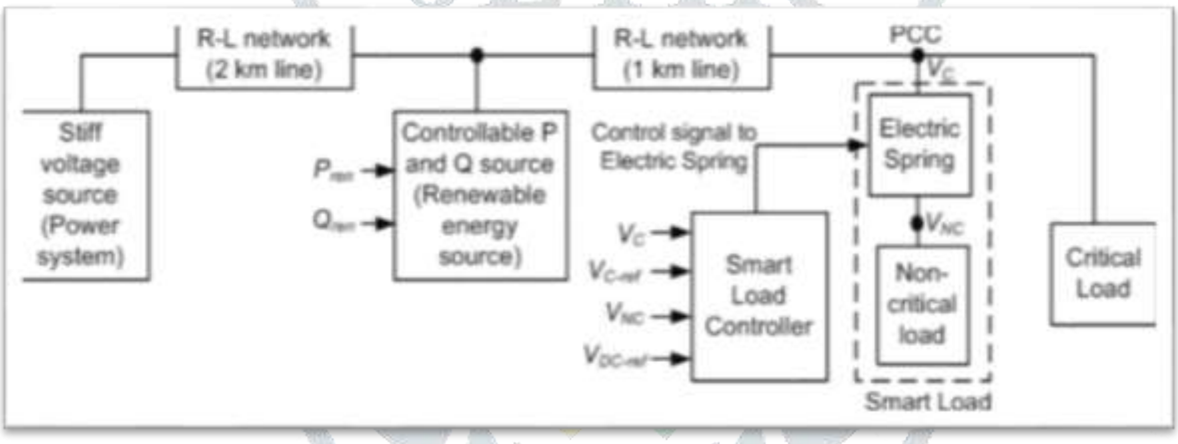

Fig 4:block diagram of eletrical spring

Fig.4 shows the diagram of the general test system which is modelled in MATLAB/SIMULINK. A voltage source is employed to model the majority power grid . The active and reactive power fluctuation from the renewable energy source (Pren, Qren) is modelled by a controllable current injection at the purpose of reference to the network. The amplitude of the present is decided by the active and reactive power exchanged. Two segments of the network are modelled by lumped R-L equivalent. The smart load comprising the ES and a resistive non-critical load serial and therefore the critical load are connected at the PCC. The smart load controller controls the voltage injected by the ES serial with the non-critical load. For simplicity, both the critical and non-critical loads are assumed to be purely resistive to start out with. Towards the top of Section V, simulation results for resistive - inductive (RL) loads with 0.95 (lagging) power factor is presented to point out the validity of the model.

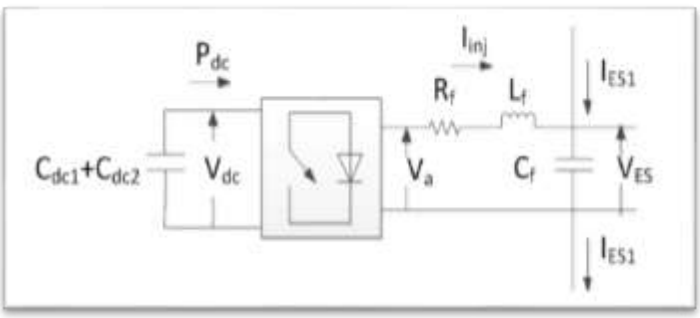

Fig:5 Power circuit of Electric Spring

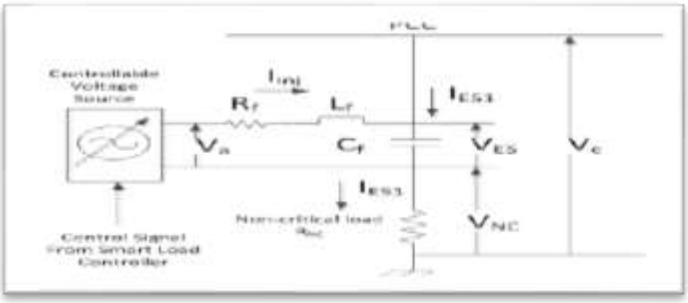

Fig: 6 Model for the power circuit of Smart Load and Electric Spring

III. Topological overview

Figure 7 shows a block schematic of the ES controller modelled in MATLAB/SIMULINK. The converter merely exchanges reactive power with the AC system since the DC bus dynamics and losses are ignored. As a result, the phase angle of the injected voltage is 90 degrees with regard to the phase angle of IES1 (depending on the sign of the mismatch between the reference and measured value of VC).

As shown in Fig. 8, a single-phase phase locked loop (PLL) is used to determine the phase angle of *IES1*.

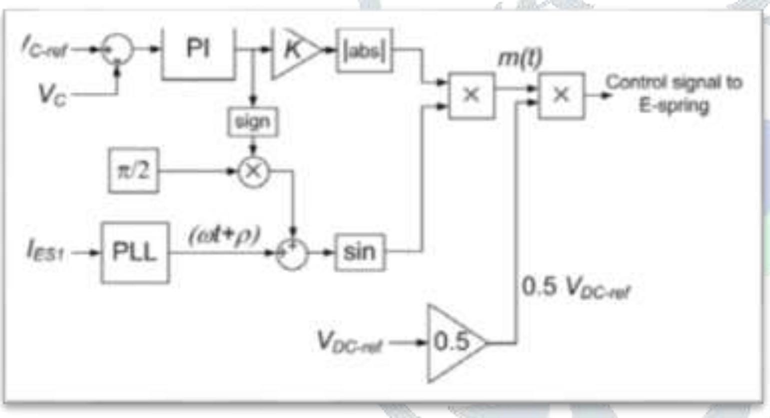

Fig 7: simulink model for Electric Spring Controller

The output of a PI compensator, which drives the difference between reference PCC voltage (VC-ref) and measured PCC voltage (VC) to zero, determines the size of the modulation index (M). A scaling factor (K) is employed to keep the PI controller's output within 1. It's worth noting that the PI controller is a discrete controller with a 20-ms sampling timeThe control signal is calculated by dividing the product of the modulation index magnitude (M) and the phase-shifted sinusoidal signal by half of the DC link voltage, which is considered to be the same as the DC link voltage reference(VDC-ref).

APPENDIX

System and Loads	
Nominal Phase voltage (V1)	220 Vac
Non Critical Load Resistance (Ra)	50.5Ω
Other/ Critical Load Resistance (R)	53.0Ω

Network Box		
Distance	Resistance	Inductance (ḿḢ)
1km	0.1	1.22(ḿḢ)
2km	0.1	2.4(ḿḢ)

90KVA Power Source	
Open Circuit Voltage (Eg)	430
Short Circuit KVA (SSC)	36KVA
Short Circuit Impedance (Zg)	5.0
Transformer Reactance Ratio (X/R)	10
Equivalent Output Resistance (Rg)	0.5Ω
Equivalent Output Inductance (Lg)	16.3(ḿḢ)

Renewable Energy Source Simulator		
	Active Power (W) injected to thr grid	Reactive power (Var) injected to the grid
Steady state conditions @= 220Vac	250W	467Var (inductive)
Pre-recorded Active and Reactive Power Profile	250W	Reactive Power Profile

Electric Spring Power Circuit			
Inverter Topology	Single Phase Half Bridge Inverter		
Switching Frequency	20kHz		
Regulated DC- Bus Voltage	400Vdc		
DC Bus Capacitance	C1=3000µF, C2= 3000µF		
Inverter Output Voltage Range	0~134vac, Controlled by the Modulation Index		
Power MOSFET	IRFP31N50L		
Typical R_{DS} (m)	0.15Ω @ Id=31A		
Output Low Pass Filter			
Measured inductance:	500µH@100Hz		
Measured Equivalent Series Resistance	3Ω@100Hz		
Capacitance	13.2µF		
NI Embedded Controller			
Switching Scheme:	Sinusoidal PWM		
Minimum to maximum duty -cycle	0.05 ~ 0.95		
Proportional and Integral controller	Sampling Time (Ts)	Proportional Gain (Kp)	Integral Gain (KpKi/Ts)
AC line Control Loop	20ms	30	5
DC bus Control Loop	20ms	20	1

RESULT:

Electric spring has following three different operating modes:

A. Voltage Support Mode:

The reactive power consumed by the intermittent source was raised to demonstrate the ES's voltage support capacity. As can be seen from the blue (solid) lines in both simulated responses in Fig. 6.1, without ES, the line voltage drops below its nominal value of 220 V. With ES, the line voltage immediately returns to its nominal value, as seen in simulation results.

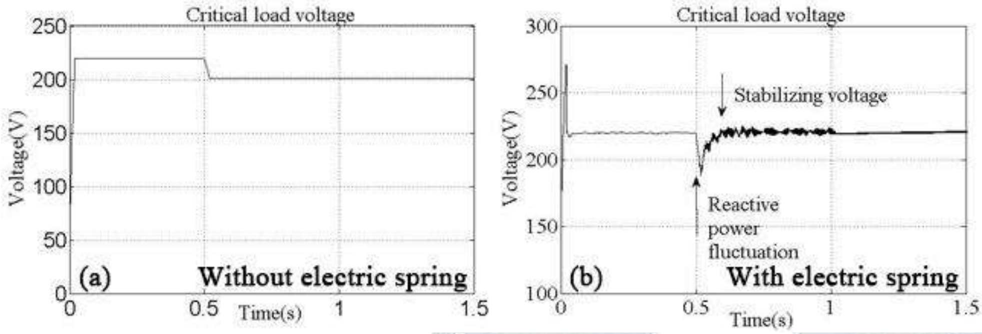

Fig.A: Voltage Support Mode for critical load

B. Voltage Suppression Mode:

An rise in line voltage was generated by reducing the reactive power consumed by the intermittent source to test the ES's voltage suppression capability. The blue (solid) lines in both simulated responses in Fig. 6.2 with ES show that this results in a rise in line voltage over its nominal value of 220 V without ES, Both simulation and practical data show that the line voltage is soon suppressed back to its nominal value.

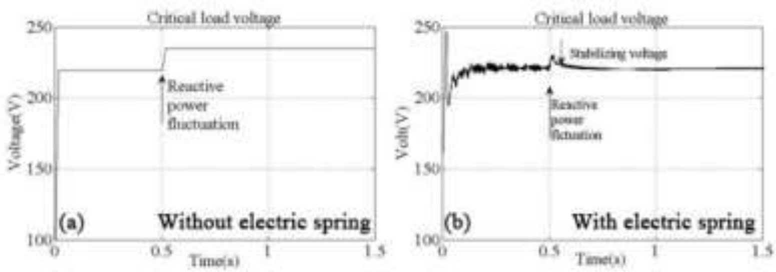

Fig. B: voltage reducing mode for critical load

C. Normal operating mode:

If the mains (supply) voltage meets the requirement of electric spring then there is no busting or reduction of voltage in the system.

IV.CONCLUSION

The application of renewable energy can effectively alleviate the contemporary energy crisis and reduce the environmental pollution. But, it also generates considerable reactive power volatility to the grids and lowers voltage quality. By application of electrical spring, these problems are often overcome.

The electric spring may be a new technology that has attractive features including dynamic voltage regulation, balancing power supply and demand, power quality improvement, distributed power compensation and reducing energy storage requirements for future smart grid.

The efficiency of an ES improves as the percentage of non-critical load increases. The simulation model is straightforward for inclusion into large-scale system simulation platforms and yet accurate enough to capture the dynamic behaviour of interest in terms of studying voltage and frequency stability.

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