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Advance Control Scheme for Correction of Power Factor and Voltage Stability by Using Electric Spring

G Jahnavi Chowdary, S. Palani Kumar

Abstract: ***A novel smart technology has been introduced in the demand side management which can be used in real time i.e., electric spring. This electric spring provides voltage, power stability and found to be useful in maintaining the voltage supply in spite of the fluctuations caused by the intermediate nature of renewable energy sources and implemented in conjunction with non-critical loads and critical loads like electric heaters, refrigerators, laptops, building security systems. To get better power factor correction, voltage support, power balance in loads, using the properties of PLL through single phase d-q transformation scheme is developed. In order to improve power-factor and voltage stability, fuzzy control scheme is proposed in this paper. By using Fuzzification control scheme, power factor at loads, voltage stability of the system can be achieved. The integration of electric spring in sequence to non-critical loads forms a smart load. Thereby alteration of active power and reactive power is done automatically near non-critical loads. Simulation results are carried out for ES based on PLL control by using fuzzy logic controller and their results are analyzed.***

Index Terms: ***Fuzzification, Electric Spring, Critical loads, Non-critical loads, Voltage stability, Renewable energy sources, Power quality.***

I. INTRODUCTION

With limited availability of fossil fuel such as coal and petrol, power generation has been decreasing day by day but on the other hand human invention such as home appliances are increasing gradually and this makes to generate more amount of power to meet demand. Numbers of power based appliances are increasing as every object is based on its new trends of technology. So, for all these things it requires generating more amount of power and should have knowledge to distribute power among various types of consumers. During the process of power distribution, Industrial consumers, commercial consumers are not satisfied due to power impacts. In order to make them satisfy demand side management has been implemented, which reduces the power consumption during the peak hours of the day. There are various types of demand side management techniques [1] such as load scheduling, direct load control, energy storage devices, but all these do not show any impact on real time. With the availability of large intermitted natural resources such as wind energy, solar energy it can generate more power, but here the storage of this power has become a major problem. When the power generation is more electric spring is used for storage of energy and the direct injection of power into grid, these have the ability to stabilize the gird. These electric springs can use on the source side when they are connected to the grid as well as the load side. By connecting this ES to the conventional grid, the grid becomes active, self-healing and flexible.

In present days, small distributed power stations are built closer to the intermitted renewable energy sources of low ratings which can supply power to solar houses, hybrid cars etc., by providing efficient power to the loads.

A spring is a rigid object which repels based on their applications, that works on the principle of HOOKE's law [2]. Spring is made of high yield strength elastic material to restore energy. Electric spring is analogues to the mechanical spring. Generally a spring can be used as a storage device, for reducing the effect of shocks and vibrations, pollution free, easy maintenance. In daily life, applications of spring are pogo stick, trampoline, and spring mattresses. Electric spring helps to provide continuous voltage for non-critical loads such as house-hold appliances.

Whenever there is more generation of power through renewable sources, battery banks, super capacitors [3] are introduced to store power. The life time of these storage devices are low, and the cost of the battery is directly proportional to the capacity of the battery. Though they are unable to balance voltage supply and decomposition of batteries causes environmental problems. In such a case electric spring are introduced and can be used as energy storage devices. By connecting renewable energy sources along with electric spring to the grid [4], frequency, voltage stability can be maintained easily. It allows power demand based on its power generation. When connecting these renewable energy sources to grid, these energy sources do not have interruption of power supply so there will be voltage stability in grid. For any ac system especially for house hold appliances and industrial loads power factor is required, for house hold appliances power factor close to unity is required in order to reduce losses in the transmission lines and thereby reducing the cost of electricity bills also. For industrial loads power factor is required to improve the efficiency of equipments. For improving power factor various power factor correction methods such as passive capacitors, shunt condensers are used. For improving of power factor through electric spring various methods has been introduced such as by using PWM techniques, phase locked loops using the properties of d-q transformation but it does not make power factor close to unity, system makes complex and time consuming.

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When electric spring is implemented with fuzzy makes the power factor of the system close to unity. In general, the advantage of making power factor close to unity in ac systems is to ease the losses, improve the effectiveness of the system and improve the life of the equipments etc. With the advancement of power electronics devices [5] such as STATCOM, SSSC are used for power factor corrections. But this device does not have input power control. These power electronic devices are similar to the electric spring, and differ through: power electronics devices which control output power based on output feedback, whereas this electric spring can control input power based on input feedback. Power electronic devices cannot alter between active and reactive power where as this electric spring can alter between active and reactive power. Electric spring can automatically adjust to load changes in the non-critical loads

For the implementation of electric spring there are many control algorithms and control techniques used. Some of the Control algorithms such as radial chordal decomposition (RCD) control [6] and novel $^{\delta}$ control are used [7]. The RCD algorithm is based on the basic trigonometry, principles of all electrical components, requires multiple numbers of inputs such as phase information, magnitude of the local grid voltage. Novel $^{\delta}$ control requires electrical parameters of the simultaneous circuits. This makes system complex. Control techniques such as sinusoidal PWM technique, internal PLL using d-q transformation properties are used, but in this control techniques the comparison of pulses is time taking. In order to reduce this complexity and to increase the response of the system a new technique has been implemented i.e., through fuzzification.

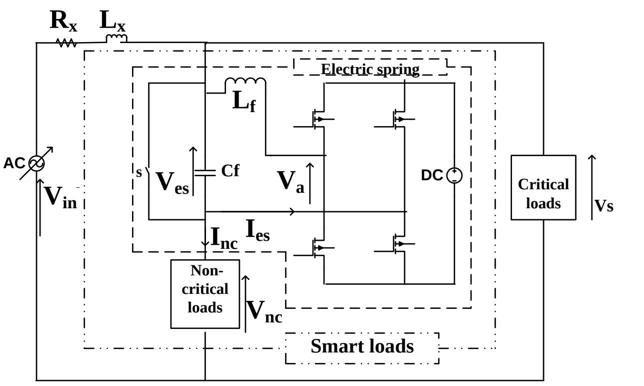

Fig.1: schematic diagram of electric spring.

Loads are mainly classified into two types there are

1. **Critical loads**: This requires constant voltage source like building security systems, Hospital equipment such as E.C.G, C.C.G.
2. **Non-critical loads**: This can endure some degree of voltage fluctuations like electric heaters, refrigerators.

In this paper Fuzzy logic is implemented in electric spring for energy storage, to improve power factor and to improve voltage stability. In order to minimize the power fluctuations a fuzzy logic system for decision making is introduced. It allows the consumer to accomplish real time operation and maintains scheduling.

II. OPERATING PRINCIPLE

ES can be realized as self power device; by using ES power quality is maintained in the circuit and limits the harmonics. From Fig.1 shows ES comprises LC filter with four MOSFET's. This full bridge rectifier [8] rectifies AC voltage into DC voltage and this energy is stored across bulk capacitor. Fuzzification method is adopted to charge and discharge the voltage present in the capacitor during swag and swell cases. The output obtained from the rectifier is the output of ES. ES can alter between active power and reactive power. The operation of electric spring is studied under two scenarios.

(a) Slag case: when the line voltage is under the reference voltage by 10 % to 90% for a time period of 0.5sec. This case occurs when the supply voltage is less and the demand is more. In under voltage case the voltage is less so injection of reactive power is done by controlling the switch in order to provide continuous power supply. There by energy stored in the ES is used by the non-critical loads [9].

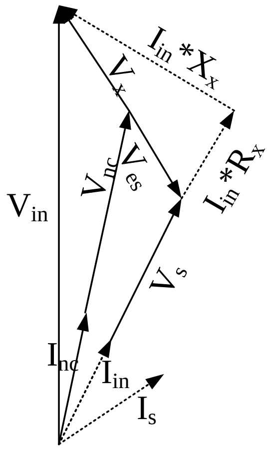

Fig.2: Slag case.

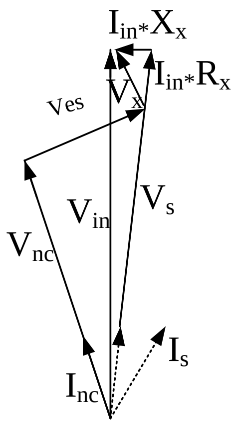

Fig.3: Swell case.

(b)Swell case: when the line voltage is above the reference voltage by 10% to 80% for a time period of 0.5sec. This over voltage condition occurs during the no-load condition, fault condition. When the intermittent renewable energy is fed to the system generates more amount of power. In this case Demand is less and generation is more, ES stores energy.

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III. CONVENTIONAL ELECTRIC SPRING

In conventional electric spring PWM technique [10], there are different types of PWM technique such as sinusoidal PWM technique, triangular PWM technique. For sinusoidal PWM technique the required parameter are m (modulation index), θ (phase angle). Modulation index (m) is considered by taking the voltage from critical load and the suggested voltage. The variation between critical load and the suggested voltage is considered as error voltage (V_e). To eliminate the error signal, PI controller is used and obtained output is taken for calculation of modulation index (m). Depending upon the non-critical load voltages, i.e., over voltage or under voltage the value of θ is calculated. By using these parameters the required output $V_{pwm} = m \sin(\omega t+\theta)$ is calculated for PWM technique. The pulses that are generated from the PWM are given to the MOSFET's in the electric spring. Depending on these pulses, the under voltage cases or over voltage cases can be determined.

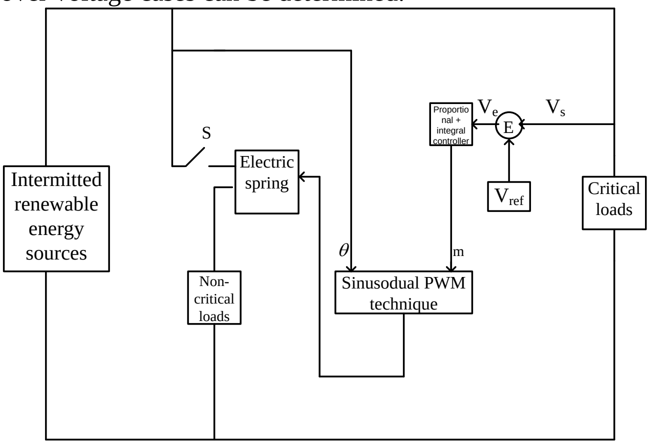

Fig.4: Conventional ES.

IV. IMPROVISED ELECTRIC SPRING

For the implementation of contrived ES, consider d-q transformation which is time independent. This d-q transformation used in 3- φ system is same as 1-φ d-q transformation. This is used to have clear examination and command over the system. The notations used for three phase are same in single phase. For single phase d-q transformation it requires two variables, these two variables are generated by using second order generalized integral (SOGI) [11]. These two variables are alike, but differ by 90 degree phase shift. The internal phase locked loop (PLL) [12] can be generated by using the properties of 1-φ d-q transformation [13]. By using PLL one phase input of the SOGI becomes zero with some phase error even under magnitude frequency changes. This PLL has small control on voltage / current injections and more important to measure voltage and current. To Eliminate this errors, PI controller is used. The obtained output from PI controller is converted to real and imaginary and these signals are given to MOSFET's.

By using this technique, power factor is poor in over voltage case and this increase the losses in the system. To operate ES it requires more time, during the over voltage (or) under voltage case. For PI controller the gain values are fixed and cannot change the gain values, if gain values changes the output of the system is not stable, and system stability decreases. To improve the stability of system several steps are involved and this makes the system complex.

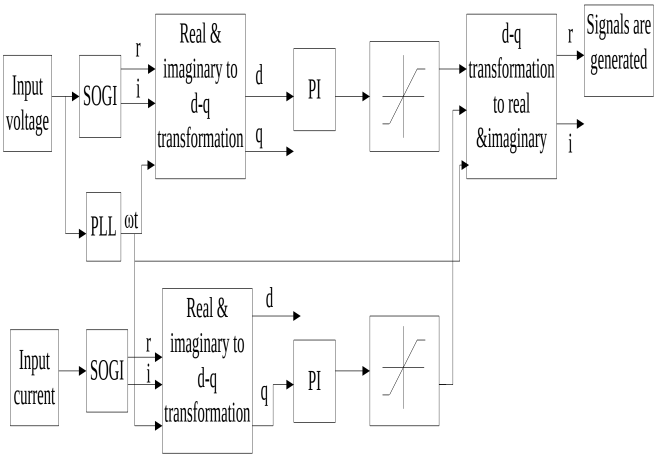

Fig.5: Generation of pulses for MOSFET's.

V. PROPOSED MODEL

Fuzzy algorithms are used to solve complex systems and decision processes. It can be simply described as *control with sentences rather than equations*. With the implementation of fuzzy can avoid complex mathematical equations. This fuzzy are based on logical rules such as AND logic, OR logic etc.,

In order to contrive the power factor in slag case fuzzification control scheme is used. Fuzzy helps to map inner variables to the outer variables. The main objective for the implementation of fuzzy is by making a list of if-then statement called "Rules.

In Fuzzy inference systems there are two types namely- 1.Mamdani, 2.Sugeno. Mamdani method is built by using fuzzy set theory in which the outer member ship are crisp values , where as Sugeno is the model based on inference system.

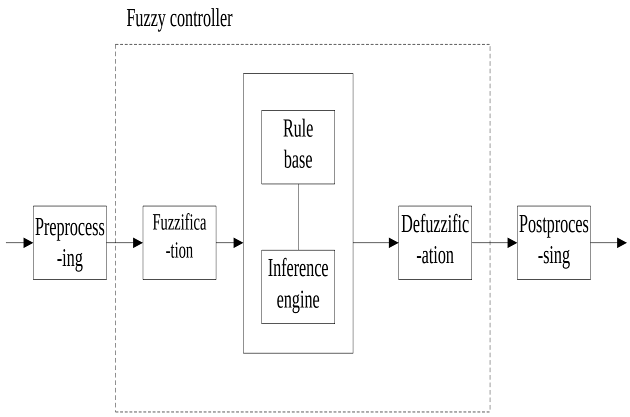

Fig .6: Fuzzification process.

In MATLAB, implementation of fuzzy is based on importing and exporting. For implementation of fuzzy there are 49 rules, some of them are

1. If e is NB and C_e is NB then the output is NB
2. If e is NB and C_e is NM then the output is NB

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A. Membership Functions:

Table-I: Member ship function during various voltage condition.

e /ce	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	**NB**	**NB**	**NB**	**NM**	**NS**	**Z**	**NB**
NM	**NB**	**NB**	**NB**	**NM**	**NS**	**Z**	**PS**
NS	**NB**	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**
Z	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
PS	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**	**PB**
PM	**NS**	**Z**	**PS**	**PM**	**PB**	**PB**	**PB**
PB	**Z**	**PS**	**PM**	**PB**	**PB**	**PB**	**PB**

Where e is the error, C_e is the change in error, NB is the negative below, NM is the negative medium, NS is the negative small, Z is the zero, PS is the positive small, PM is the positive medium and PB is the positive below.

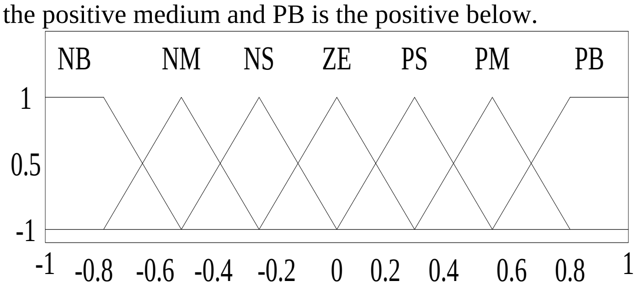

Fig. 7: Membership Functions.

VI. SIMULATION RESULTS

In slag case the rms line voltage is 218V and is turned ON at t=0.5sec. In order to maintain at 230V as shown in fig.8, ES absorb real power of 1100W (Fig.10) and injects reactive power of -2750VAR (Fig.11). the power factor of the system improves from 0.955 to 0.98 as shown in fig.9.

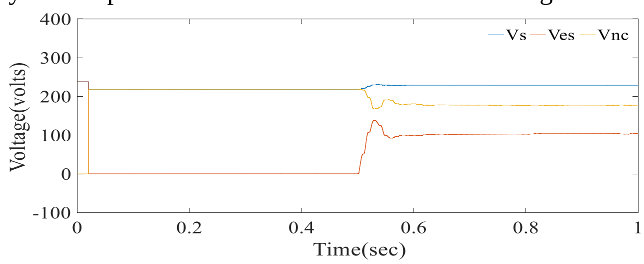

Fig. 8: Slag case, contrived ES: RMS line voltage, ES voltage and noncritical load voltage

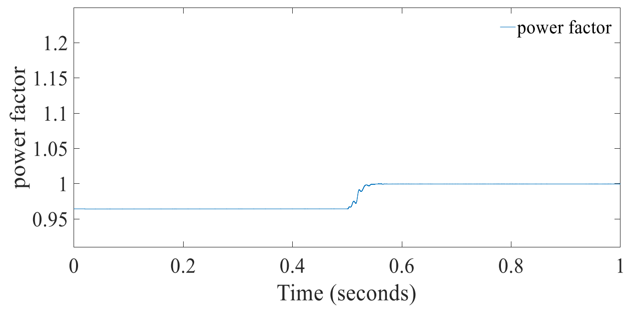

Fig. 9: Slag case, contrived ES: Power factor of the system

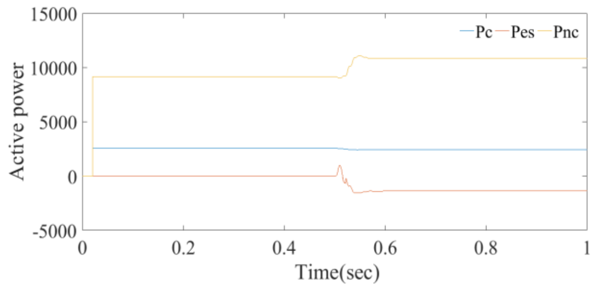

Fig.10: Slag case, Contrived ES: Active power of the system.

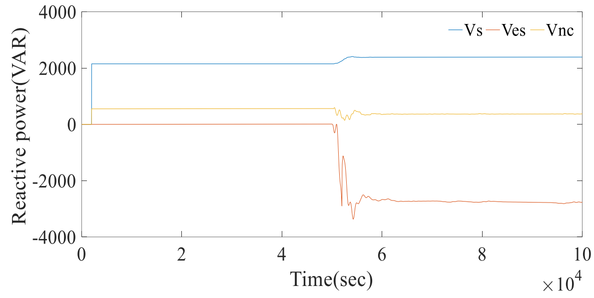

Fig.11: Slag case, contrived ES: Reactive power of the system.

Contrived ES can inject both real and reactive power into the system. In the swell case the line voltage is 238V and turned ON at t=0.5sec. In order to maintain constant 230V, ES injects real power of 1500W (Fig.14) and reactive power of 1500VAR (Fig.15) to critical loads. As a result power-factor during the swell case is decreased from 0.965 to 0.929 as shown in fig.13.

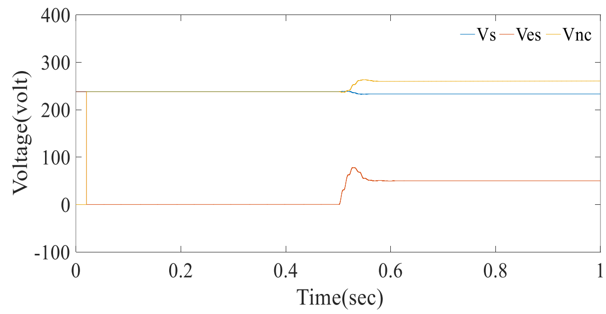

Fig. 12: Swell case, contrived ES: RMS line voltage, ES voltage and non critical load voltage.

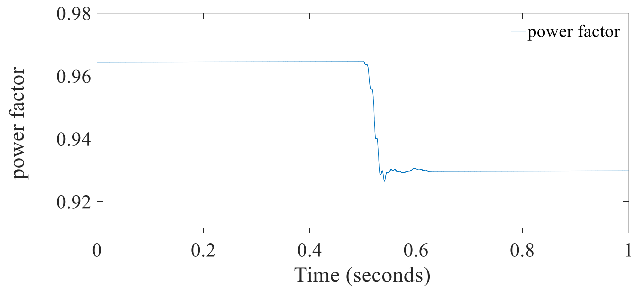

Fig. 13: Swell case contrived ES: Power factor of the system.

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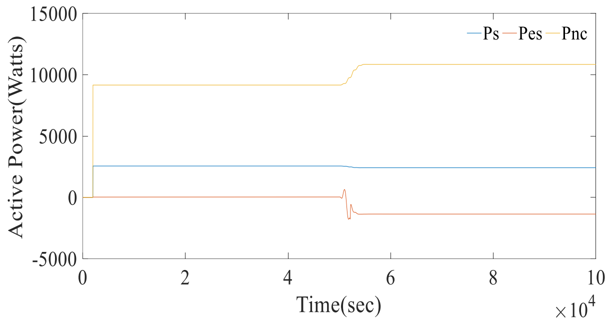

Fig.14: Swell case contrived ES: Active power of the system.

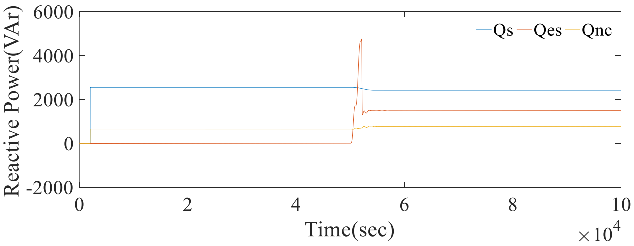

Fig.15: Swell case Contrived ES: Reactive power of the system.

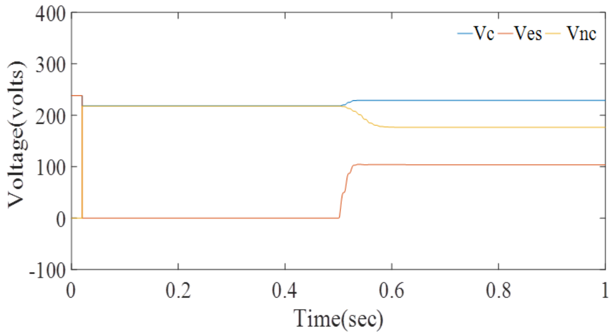

Fig. 16: Slag case, fuzzy ES: RMS line voltage, ES voltage and non critical load voltage.

In proposed ES similar to contrive ES both real and reactive power are injected. In slag case the line voltage is 218V and turned ON at t=0.5sec as shown in fig.16. In order to maintain at 230V constant ES injects active power of 1100W (Fig.18) and reactive power of -2750VAR (Fig.19). In this case power factor closes to unity as shown in fig.17.

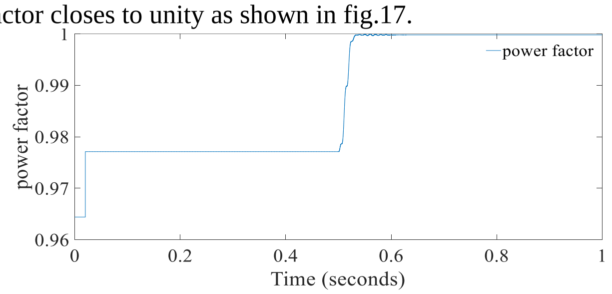

Fig.17: Slag case, fuzzy ES: power factor of the system.

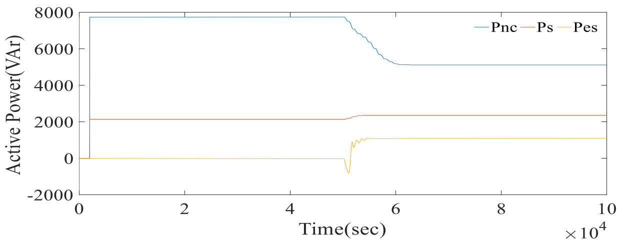

Fig.18: Slag case, fuzzy ES: Active power of the system.

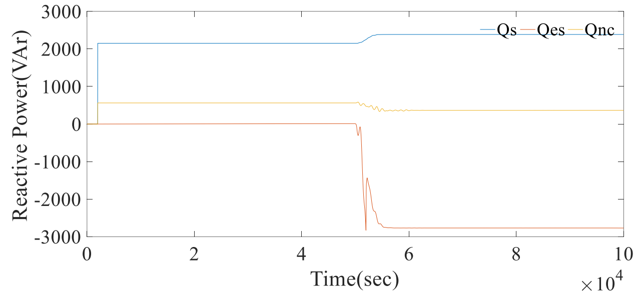

Fig.19: Slag case, fuzzy ES: Reactive power of the system.

In swell case the rms line voltage is 238V and ES is turned ON at t=0.5sec as shown in fig.20. In order to maintain at 230V ES injects active power of -2230W (Fig.22) and absorbs reactive power of 1500VAR (Fig.23). As a result power factor is improved from 0.93(from contrived ES) to 0.968 as shown in fig.21.

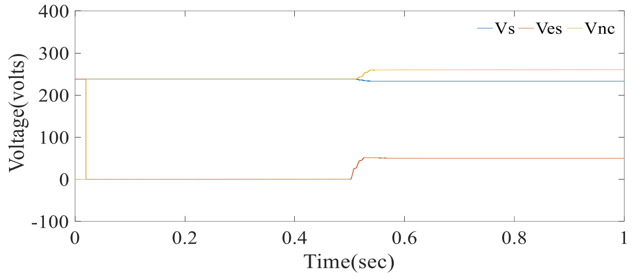

Fig.20: Swell case, fuzzy ES: RMS line voltage, ES voltage and non critical load voltage.

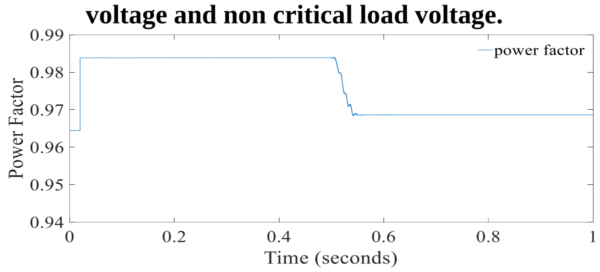

Fig.21: Swell case, fuzzy ES: power factor of the system.

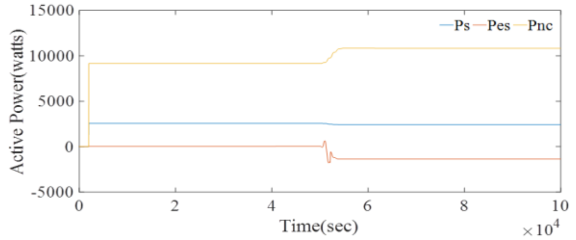

Fig.22: Swell case, fuzzy ES: Active power across the loads.

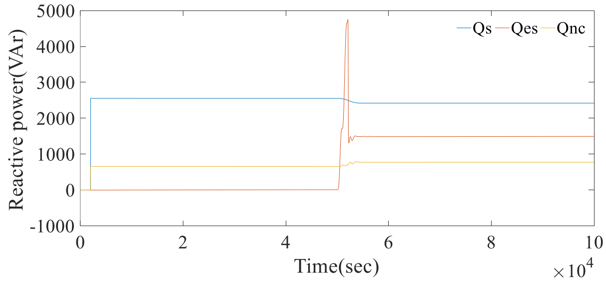

Fig.23: Swell case, fuzzy ES: Reactive power of the system.

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VII. SPECIFICATIONS

Table-II: Specifications of Electric Spring

Name of the device	Rating of the device
Inductor	1.92mH
Capacitor	13.2µF
Dc voltage	400V
Inverter topology	1-phase (ϕ) full bridge inverter
Switching frequency	20KHZ

VIII. COMPARISON TABLE

Table-III: Power factor during various voltage conditions.

Type of controller	Power factor	
	slag	swell
Conventional ES	0.97	0.895
Improvised ES	0.98	0.93
Proposed ES	0.99	0.97

Table-IV: Voltage stability between the loads (when ES is turned on at t=0.5sec).

Case	Conventional			Improvised			Proposed		
Swell	.6	.68	.62	.55	.58	.6	.52	.52	.52
slag	.63	.68	.64	.58	.62	.66	.51	.51	.55

IX. CONCLUSION

Electric Spring charging /discharging process increases the storage, efficiency, reduces the cost when compared to the battery by using intermitted renewable energy sources. The simulation of electric spring between the loads is successfully accomplished by using fuzzy logic controller without any power interruption. The fuzzy logic controller gives better response for improving power factor close to unity when compared to internal PLL using d-q transformation properties. In the future analysis another control such as artificial intelligence technique can be used for better performance.

APPENDIX

V_{in}	Input voltage
I_{in}	Input current
V_{nc}	Voltage at non-critical loads
I_{nc}	Current at non-critical loads
V_s	Voltage at critical loads
I_s	Current at critical loads
V_{es}	electric spring voltage
I_{es}	Electric spring current
V_x	Voltage across line impedance
$I_{in}*X_x$	Input voltage line impedance
$I_{in}*R_x$	Input voltage line resistance
ES	Electric spring
PLL	Phase locked loop

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