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A Broad Survey on Electric Springs for Flexible Load Management in Smart Grid

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***Abstract*—Smart grid technologies are emerging technology and it is said to be the integration of electrical network and communication technology. This paper deals with survey of various problems related to the Smart Grids and recently proposed concept of electric springs used to compensate those problems. Flexible Alternating Current Transmission Systems (FACTS) devices helps in present transmission and distribution lines to deliver maximum power and helps to stabilize the grid with precise voltage control. Electric springs are said to be built from Hooke's law published three centuries ago. They are power electronics-based reactive power controllers which are used to regulate the power and voltage and overcome the disadvantages in Facts devices. This concept is mainly used in the power grid which are connected to the distributed energy sources as they are intermittent in nature.**

Keywords— smart grid; electric springs; distributed energy sources; reactive power controllers, facts devices

I. INTRODUCTION

Emerging technologies of smart grid seems to be the solution for the engineers who face the challenges in reducing the faults and losses in Transmission &Distribution.Efficient distribution of energy with the power electronic devices helps to generate electricity. The increase in intermittent and distributed renewable energy sources has raised concerns about the stability and eliminating the losses of future power grid. These renewable resources are mainly given by very fluctuating and uncontrollable solar, hydro and wind power. The generation resulting from these sources may have some similarities with the electricity demand, but they are in general far from being same. For this reason, generation is required to be balanced with the demand and supply resulting in a fluctuating generation .The effect of fluctuations in demand side is due to the decrease in generation efficiency [1].

For emerging smart grids connected with intermittent and distributed renewable energy sources, the new requirement of control strategies will be for the load demand to equal the power generation [2], [3]. This new requirement has invoked new research into modern demand-side management [4]. Literature review for the period of 2005–2012 showed that demand-side management [6] can be broadly summarized as follows:

- scheduling of delay-tolerant power demand task[4]–[5];
- make use of energy storage to increase peak demands [6];
- real-time pricing [7]–[8];
- direct load control or on−off control of smart loads [9]–[10]

Although these strategy have their own positives, they also suffer certain limitations.

In this survey paper, deals a new approach to demand-side management based on the electric spring (ES) term are explained.ES serves as a reactive power controllers [11], [12].It is connected series with noncritical loads such as electric water heaters, lighting systems and formed them as a smart loads. They provide reactive power and real compensation for regulation of ac voltage of the grid. The main concept was described in [12]. Similar research led to the theoretical analysis of the ES concept, which had the methodology to control both active and reactive power [13] and reduction of energy storage requirements in a grid using ES [14].The first ever paper [15] that gives a detailed and practical hardware design and control implementation of an ES for voltage regulation of distribution line in a grid. It is tested in a real time power grid fed by an intermittent wind power. It stabilizes a fluctuating ac power and analysing the load demand to follow the wind power generation are done. The differences among the ESs and various FACTS devices like static var compensation (SVC) and static compensator (STATCOM) are also included in this paper.

II. BASIC PRINCIPLE OF ELECTRIC SPRINGS

A. Analogy to mechanical spring

Hooke's law [16] states that the force of an ideal mechanicalspring is as follows

$F = -kx$

where F is the force vector, k is the spring constant, and x isthe displacement vector.

The electrical spring are compared Analogous to a mechanical spring, an ES is an electric device that can be used to:

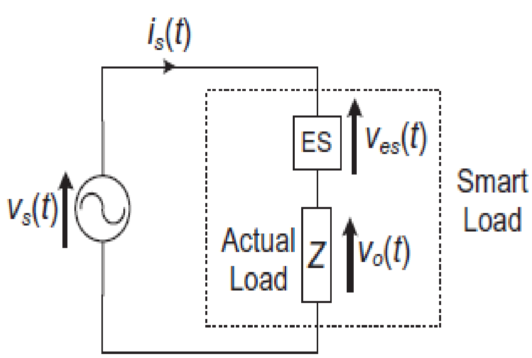
- provide voltage support;
- to store electric energy;
- damping of electric oscillations.

The basic physical relationship of the ESis expressed as [14] follows:

$$q = -Cva$$

where q is the electric charge stored in a capacitor with capacitance C, Va is the electric potential difference across the capacitor. The capacitor C serves as the energy storage element for the ES.Therefore, the oscillations of the ES can be practically realized withthe use of solid state electronics-based reactive power controller.

Figure.1. Overview of smart load



B. Smart load

The overview of smart load consists of an ES and the actual load Z Fig.1. The ES is a power electronic interface that generates an ac voltage $V_{es}(t)$ to behave as a series compensator to modify the applied voltage of the actual load $V_o(t)$, thus it directly affects the composition of real and reactive powers flowing to the load. It can be embeddedin electric appliances which are non-linear forming a smart loads which are adaptive to the power grid. They could provide high support for the smart grid, similar to that of mechanical springs supporting the mattress.

The smart load is interfaced to an ac power source with Vs(t).

C. Difference from facts device

The normal FACT devices such as SVC and STATCOM that handle pure reactive power alone, the ES is a new smart-grid technology that can alter both active and reactive power. The structure is similar to that of a static synchronous series compensator (SSSC) [17]–[18], but it differentiates itself from a SSSC by the following factors:

- employing an input voltage control rather than an output voltage control; and
- processing the ability to change the active and reactive power in the series connected noncritical load.

The below shown figure.2 represent the simplified connection of electric spring.

Figure.2. Simplified diagram of an electric spring.

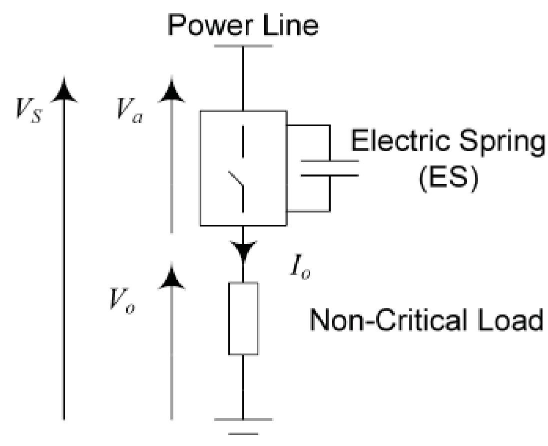


Figure.3 Vector diagrams of a) inductive mode

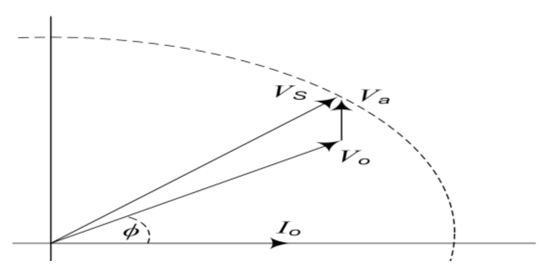
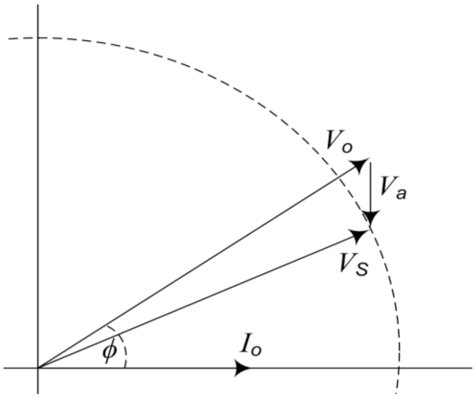


Figure.3 Vector diagrams of b) capacitive mode

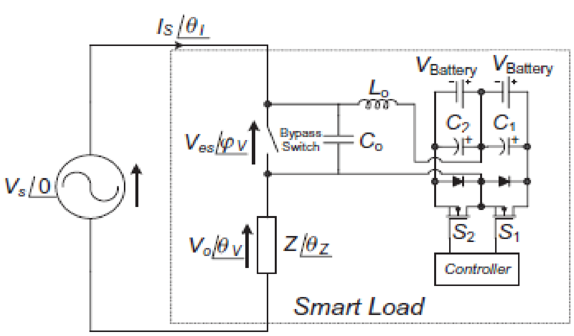


The vector representation of electric springs in its inductive and capacitive mode is shown in figure.3.

III. EXPERIMENTAL VIEWS FOR STEADY STATE ANALYSIS

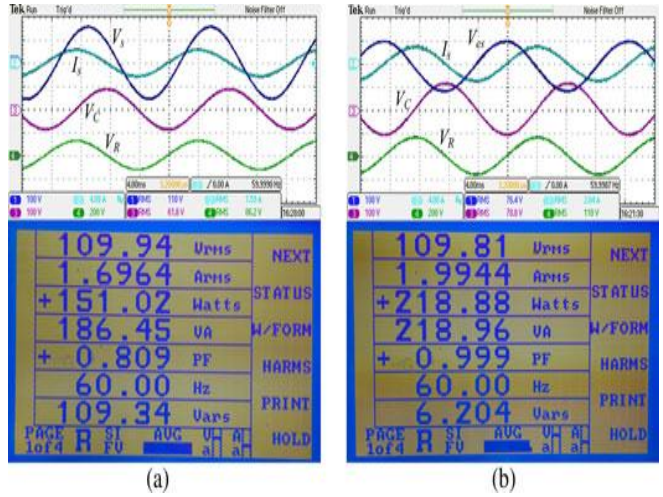
The steady state analysis [19] is done with the help experimental setup as shown in figure.4. The ES used in this experiment is a single-phase half-bridge inverter with two pair of batteries, each 240 V, used as its dc input voltage source. The bypassed switch were connected in parallel to the inverter. The turning ON of the switch can be done easily by deactivating of ES whenever power/voltage compensation was needed.For the real power compensation batteries are used of which when the ES behaves as a positive load, the batteries are charged and acts as a negative load, the batteries are discharged.The batteries can be replaced by other types of bidirectional dc voltage source or a dc/ac bi-directional power converter.

Figure.4. Overview of experimental setup



The real power absorbed by the ES is send back to the power grid through the dc/ac bidirectional power converter and conversely real power that is released by the ES is collected from the power grid. The controller used is an NI embedded controller along with SPWM control. Six experiments are performed to analyse the various problems of the ES's characteristics.

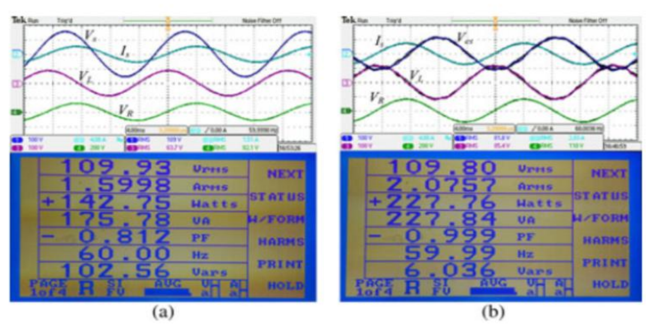
Figure. 5. Captured waveforms and data of the system with a capacitive plus resistive load of $Z = 52 - j38\ \Omega$ (a) without the ES and (b) with ES for unity power consumption.



The source power is mainly operating at nearby unity power factor (PF), i.e., the grid is supplying only real power. With the electric springsintroducingavoltage of

$V_{es} = 75.9\angle 90^\circ$ V that is in anti-phase with the capacitive load voltage of $V_C = 76\angle -90^\circ$ V, the resistive load voltage is almost equivalent to the applied voltage, i.e., VR = 104.4V. The power obtained by the system is mainly of real power of Ps = 218.88W and it is with a small capacitive power of Qs = 6.20VAr.The power factor variation before and after experimental setup can be clearly seen in the captured waveform fig.5 and fig.6 respectively which is measured by power meter [19].

Figure.6.Captured waveform with an inductive plus resistive load $Z = 56+j40\ \Omega$ (a) without the ES and (b) with ES for unity power compensation.



IV.EXPERIMENTAL SETUP FOR DYNAMIC RESPONSE

A 90-kVA power inverter unit which is controlled by a digital signal processor and it is used to emulate a traditional electric power substation present there. This experimental setup is used check the capability to improving voltage stability of a power grid which is unstable caused by the intermittent renewable power energy [15]. The prototype of that model with digital controller is done and it is shown in figure.8 in the Maurice Hancock Smart Energy Laboratory at Imperial College London. The experimental setup for evaluating the response of the ES under a weakly regulated power grid is also evaluated

Figure.8.Photos of the ES prototype and the digital controller.

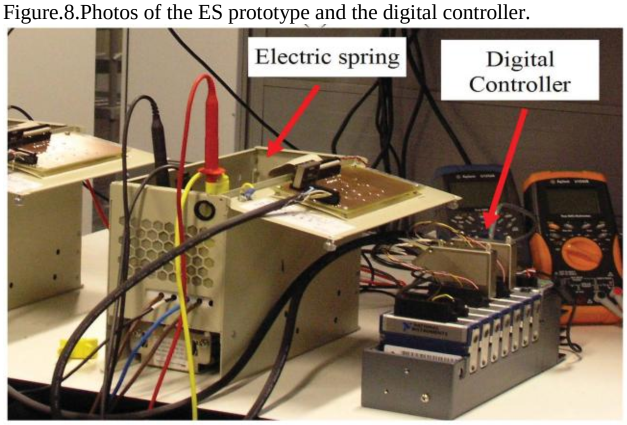


TABLE.I.

Electric Springs	SSSC
Input voltage control for non-critical load; Output voltage control for critical load	Output voltage control
Distribution level	Transmission level
Distributed	Centralized
Transformer optional	Transformed needed
Inherent balance of power supply and demand	-
Embedded in electric appliance	Separate equipment

By comparing ES with existing systems the difference can be seen and it is tabulated above table.1

V.FINAL REMARKS

The energy storage systems for balancing demand and supply are discussed. The application of the ES is targeted at electrical appliances and at a widely distributed grid. In terms of reliability and transients, the failure of a single ES will not cause a huge failure of the whole system. This paper also describes the hardware implementation of an ES to form a smart load unit. The control method for the ES for reactive power compensation real power compensation and mains voltage regulation was proposed and realized by a digital controller. The performance of the ES was analyzed and practically evaluated in a 90-kVA electric power grid. The voltage fluctuation of the power grid was created by a 10-kVA renewable energy source simulator.

ES can automatically perform voltage balance, suppression, and load-shedding functions in response to the dynamic needs of the power grid. It can be a useful apparatus for the stability control of future smart grid with intermittent renewable energy sources. The significance of this ES-based control is the fact that these can be used all over the power grid for decentralized stability control without any help of ITC, smart metering, and wide-area power management. It is a new technology that can change many noncritical loads into a new generation of smart loads that have their load demands automatically following power generation. The future research will include cost and performance comparison of ESs with all other real-time demand-side management methods.

VI.CONCLUSION

This paper clearly shows the significance of this ES-based control is the fact that these can be used all over the power grid for decentralized stability control without any help of ITC, smart metering, and wide-area power management. It is a new technology that can change many noncritical loads into a new generation of smart loads that have their load demands automatically following power generation. The reactive and real power compensation is discussed with the experimental setup. A general analysis on the steady-state behavior of the ES and the theoretical work of the concept and various control equations of the ES are discussed. It is illustrated that for a typical load of resistive, inductive, or capacitive nature. Experimental results are in equal with the theoretical analysis and derivations. This survey paper lays down the theoretical platform for future. It have the application capability for voltage regulation, improving power quality and the frequency, load stabilization of power grid through real power control of an electrical network and for the purpose of handling unpredictable load demands. The future research will include cost and performance comparison of ESs with all other real-time demand-side management methods.

REFFERENCE

[1] A. de Jong, E.-J.Bakker, J. Dam, and H. vanWolferen, “Technischenergie- en CO -besparingspotentieel in Nederland (2010–2030),” Platform Nieuw Gas, p. 45, Jul. 2006.

[2] D. Westermann and A. John, "Demand matching wind power generation with wide-area measurement and demand-side management," IEEE Trans. Energy Convers., vol. 22, no. 1, pp. 145–149, Mar. 2007.
[3] P. Palensky and D. Dietrich, "Demand side management: Demand
response, intelligent energy systems, and smart loads," IEEE Trans. Ind.
Informat., vol. 7, no. 3, pp. 381–388, Aug. 2011.
[4] I. Koutsopoulos and L. Tassiulas, "Challenges in demand load control for the smart grid," IEEE Netw., vol. 25, no. 5, pp. 16–21, Sep.–Oct. 2011.
[5] A. Mohsenian-Rad, V. W. S. Wong, J. Jatskevich, R. Schober,
and A. Leon-Garcia, "Autonomous demand-side management based
on game-theoretic energy consumption scheduling for the future
smart grid," IEEE Trans. Smart Grid, vol. 1, no. 3, pp. 320–331, Dec. 2010.
[6] M. Pedrasa, T. D. Spooner, and I. F. MacGill, "Scheduling of demand side resources using binary particle swarm optimization," IEEE Trans.Power Syst., vol. 24, no. 3, pp. 1173–1181, Mar. 2009.
[7] A. J. Conejo, J. M. Morales, and L. Baringo, "Real-time demandresponse model," IEEE Trans. Smart Grid, vol. 1, no. 3, pp. 236–242,Dec. 2010.

[8] A. J. Roscoe and G. Ault, "Supporting high penetrations of renewable generation via implementation of real-time electricity pricingand demand response," IET Renew. Power Generat., vol. 4, no. 4,pp. 369–382, Jul. 2010.
[9] S. C. Lee, S. J. Kim, and S. H. Kim, "Demand side management withair conditioner loads based on the queuing system model," IEEE Trans.Power Syst., vol. 26, no. 2, pp. 661–668, May 2011.
[10] A. Brooks, E. Lu, D. Reicher, C. Spirakis, and B. Weihl, "Demanddispatch," IEEE Power Energy Mag., vol. 8, no. 3, pp. 20–29,Jun. 2010.
[11] S. Y. R. Hui, C. K. Lee, and F. F. Wu, "Power control circuit and method for stabilizing a Power Supply," U.S. Patent 61 389 489, Oct. 4, 2010.
[12]S. Y. R. Hui, C. K. Lee, and F. Wu, "Electric springs—A new smartgrid technology," IEEE Trans. Smart Grid, vol. 3, no. 3, Sep. 2012,
pp. 1552–1561.
[13] S. C. Tan, C. K. Lee, and S. Y. R. Hui, "General steady-state analysis and control principle of electric springs with active and reactivepower compensations," IEEE Trans. Power Electron., vol. 28, no. 8,
pp. 3958–3969, Aug. 2013.
[14] C. K. Lee and S. Y. R. Hui, "Reduction of energy storage requirements for smart grid using electric springs," IEEE Trans. Smart Grid, (early access).
[15]Chi Kwan Lee, BalarkoChaudhuri, and Shu Yuen Hui"Hardware and Control Implementation of Electric Springs for Stabilizing Future Smart Grid With Intermittent Renewable Energy Sources" IEEE Journal Of Emerging And Selected Topics In Power Electronics, Vol. 1, No. 1, March 2013.
[16] (2009, Nov.). Hooke's Law—Britannica Online Encyclopedia [Online].Available: http://www.britannica.com/EBchecked/topic/271336/Hookeslaw
[17] J. Dixon L. Moran, J. Rodriguez, R. Domke, "Reactive power compensation technologies: State-of-the-art review," Proc. IEEE, vol. 93, no. 12, pp. 2144–2164, Dec. 2005.
[18] P. Sauer, "Reactive power and voltage control issues in electric power systems," in Proc. Appl. Math. Res. Electr. Power Syst. Conf., Apr. 2005, pp. 11–24.
[19]Siew-Chong Tan, Chi Kwan Lee,and S. Y. (Ron) Hui,General 'Steady-State Analysis and Control Principle of Electric Springs With Active and Reactive Power Compensations'.IEEE Transactions On Power Electronics, Vol. 28, No. 8, August 2013
[20] M. Parvania and M. Fotuhi-Firuzabad, "Demand response scheduling by stochastic SCUC," IEEE Trans. Smart Grid, vol. 1, no. 1, pp. 89–98, Jun. 2010.

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