Reduction of Energy Storage Requirements in Future Smart Grid Using Electric Springs

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ABSTRACT

The electric spring is an emerging technology proven to be effective in i) stabilizing smart grid with substantial penetration ofintermittent renewable energy sources and ii)enabling load demand to follow power generation. The subtle change from output voltage control toinput voltage control of a reactive power controller offers the electric spring new features suitable forfuture smart grid applications. In this project, the effects of such subtle control change are highlighted, and the use of the electric springs in reducing energy storage requirements in power grid is theoretically proven and practically demonstrated. Unliketraditional Statcom and Static Var Compensation technologies, the electric spring offers not only reactive power compensation but also automatic power variation in non-critical loads. Such an advantageous feature enables non- critical loads with embedded electric springs to be adaptive to future power grid. Consequently, the load demand can followpower generation and the energy buffer and thereforeenergy storage requirements can be reduced. Circuitmodels are developed for two bus system with andwithout DVR and the corresponding simulationresults are presented

Keywords: Distributed power systems, energystorage, smart grid, stability.

1. INTRODUCTION

The existing control paradigm of power systems is togenerate power to meet the load demand, i.e., "powergeneration following load demand". With the increasing use of intermittent renewable energy sources, known or unknown to the utility companies, it is impossible todetermine the instantaneous total power generation in real time. In order to achieve balance of power supply anddemand, which is an essential factor for power systemstability, the control paradigm for future smart grid has to be shifted to "load demand following power generation". Various load demand management methods have previously been proposed. Some examples include loadscheduling, use of energy storage as a buffer, electricitypricing, direct control or on-off control of smart loadsetc.However, most of these methods are suitable for loaddemand management i n the time frame of hours andare not suitable for instantaneous energy balance inreal time. Energy storage is probably the most effectivemeans for instantaneous energy balancing. In order tocope with fast transient, energy storage elements such asbattery banks are installed with parallel connected supercapacitorswhich can absorb current at a faster rate thanchemical batteries. However, energy storage elementssuch as batteries are expensive and disposed batteries aremajor sources of pollutants. Although they areconsidered to be essential elements in future smart grid,it would be preferable to reduce their size for cost andenvironmental reasons.In this project, an investigation is conducted to examinethe use of electric springs in reducing energy storageelements in future smart grid. The electric spring conceptwas recently presented as a new smart grid technologyfor regulating the mains voltage of power grid with substantial intermittent renewable power and forachieving the new control paradigm of load demandfollowing power generation.

Traditional seriesreactive power compensators use output voltagecontrol (Fig. 1); by shifting from the output voltagecontrol to the input voltage control for a reactivepower controller, electric springs demonstratecharacteristics different from traditional devices suchas series reactive power controller. The effects of thissubtle change of control methodology and theinteractions between the electric springs and energystorage in a power grid, which have not been previouslyaddressed, are highlighted with practical tests in thisproject. Unlike Statcom, Static Var Compensation, andUPFC technologies [21]–[26], electric springs offer notonly reactive power compensation, but also automaticload variation in non-critical loads (with electricsprings embedded). This advantageous featureprovides the possibility of reducing energy storagerequirements in future smart grid.

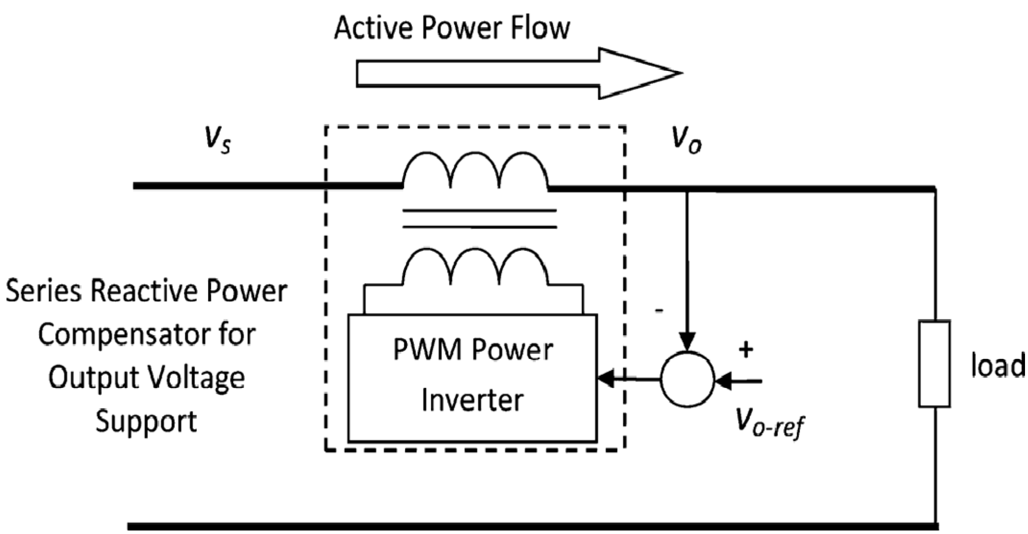

Fig. 1. “Output voltage control” of a series reactive power compensator.

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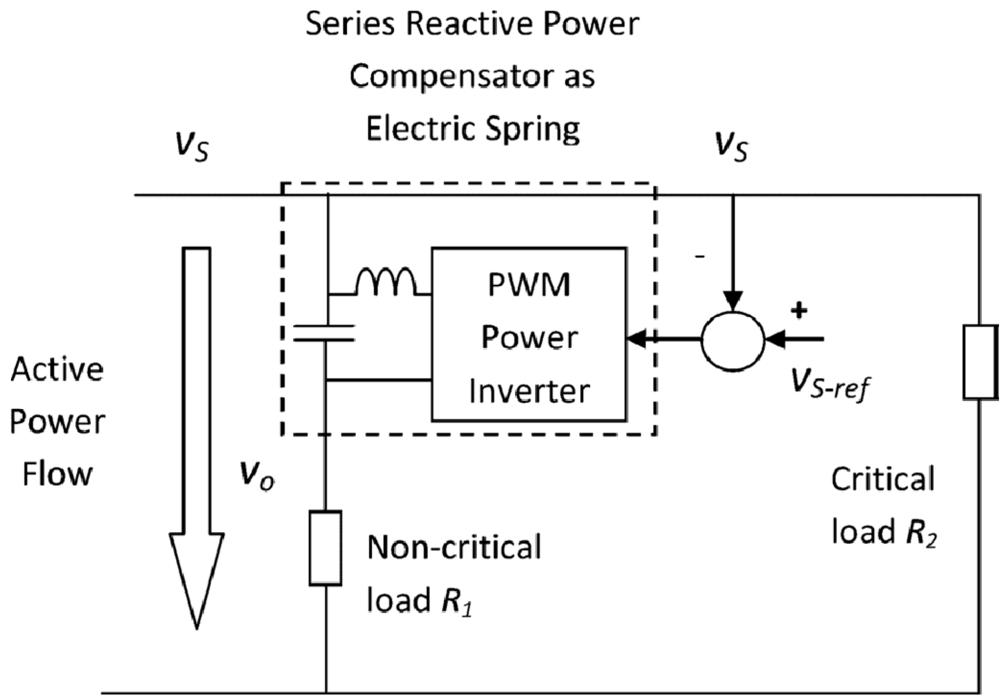

Fig. 2. Arrangement of an electric spring connected in series with a non-critical load anusing the "input voltage control") [18].

2. BASIC PRINCIPLES OF ELECTRIC SPRINGS

Electric springs are reactive power controllers withinput voltage control instead of the traditional outputvoltage control used in series reactive powercompensators. Details of the system operation canbe found in [17]. In this session, the basicprinciples of electric springs are summarized so as to facilitate readers' understanding of the power flowanalysis and the effects of the electric springs onreducing energy storage requirements in smart grid.Fig. 2 shows a typical installation of a single-phaseelectric spring connected in series with a non-criticalload. The electric spring comprises a power inverterwith a dc bulk capacitor on the dc side and inductive-capacitive (LC) filter on the ac side of thepower inverter. The four freewheeling diodes of thepower inverter behave like a diode rectifier whichrectifies the ac voltage into a dc one across the bulkcapacitor. The pulse-width-modulation switchingmethod is adopted in the power inverter to generate acontrollable ac voltage across the filter capacitor. Thiscontrollable ac voltage is the output voltage of theelectric spring. For pure reactive power control, thevector of the electric spring voltage and the currentmust be perpendicular. The input voltage control loopdepicted in Fig. 2 is designed to generate dynamicallywith the purposed of regulating the ac mains voltage toa reference value.

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3. POWER ANALYSIS OF ELECTRIC SPRINGS FOR REDUCTION OF ENERGY STORAGE

Now consider a general power grid consisting of an ac generator, a renewable power source, energy storage(battery banks), a set of non-critical loads and a set ofcritical loads as shown in Fig. 3. The power flowdiagram is shown in Fig.4 in which the power fromthe energy storage can be positive or negativedepending on whether the storage device is discharging orcharging

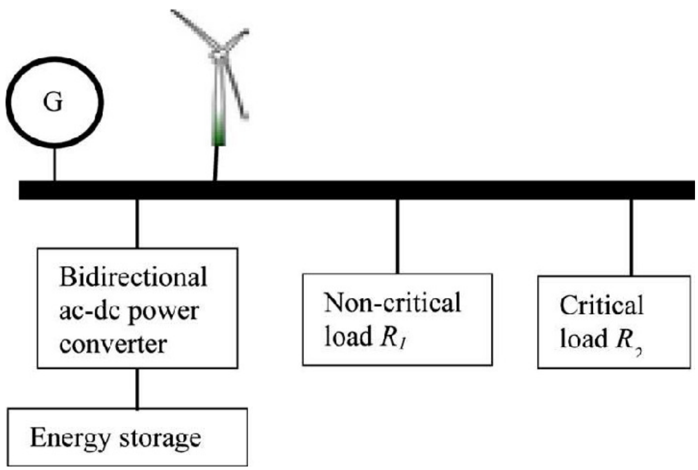


Fig. 3. Schematic of a power grid

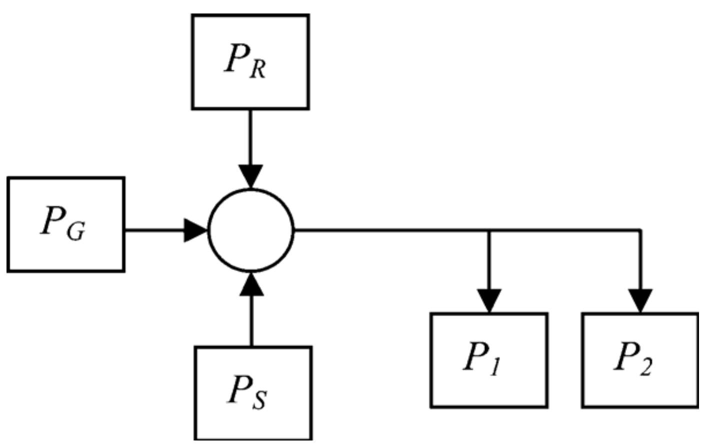


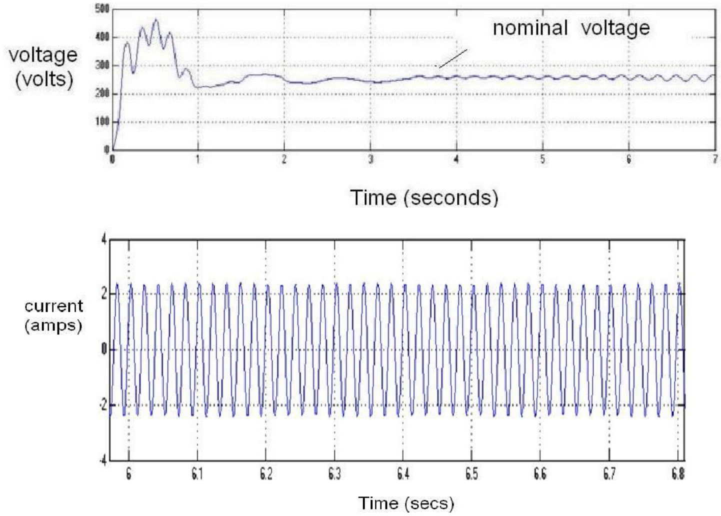
Fig. 4. Power flow diagram.

Where PG is the power generated by the ac generator, PRis the renewable power, and Ps is the power from theenergy st or age . Ps is positive when the battery isdischarging and Negative when it is charging.

4. PRACTICAL EVALUATION

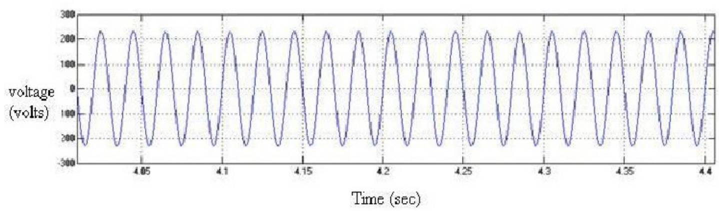
The simulation results are done with the batterysystem,wind system and for the hybrid system.

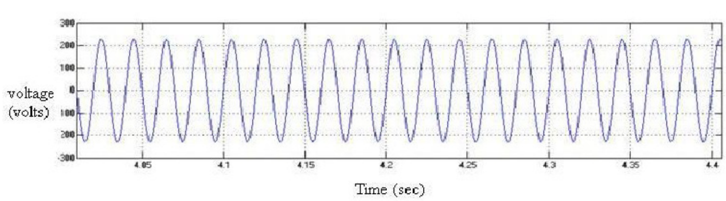
WIND SYSTEM MODEL



BATTERY SYSTEM MODEL INVERTER

OUTPUT VOLTAGE





OUTPUT VOLTAGE HYBRID SYSTEM

The reactive power profile of the electric spring underinput voltage control follows the charging anddischarging time of the battery.The voltage stays within 1% tolerance of 220v andthe power of the critical load remains essentiallyconstant with tight tolerance

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FFT ANALYSIS

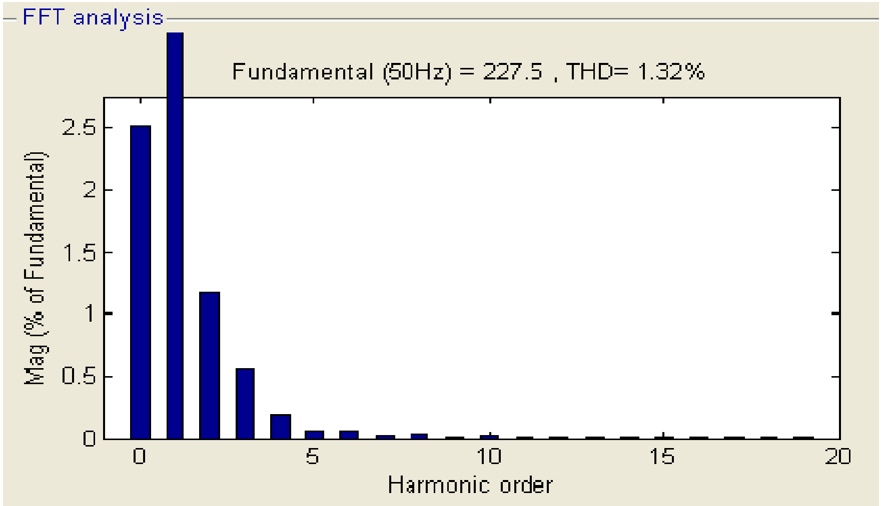

Fig .6 FFT Analysis

$$THD = \frac{\sqrt{(V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2)}}{V_1} * 100\%$$

TWO BUS SYSTEM WITHOUT DVR

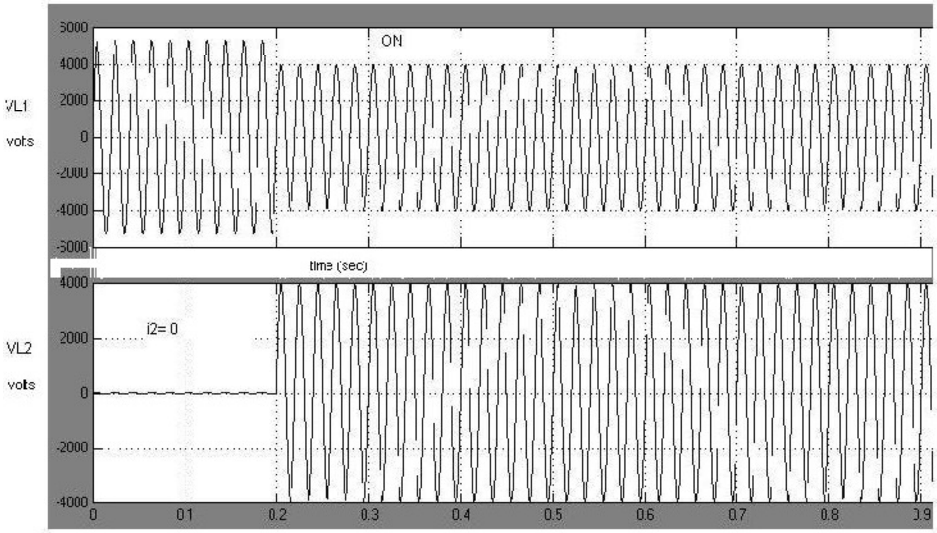

Fig7 Voltage Across Load -1 And Load -2

TWO BUS SYSTEM WITH DVR

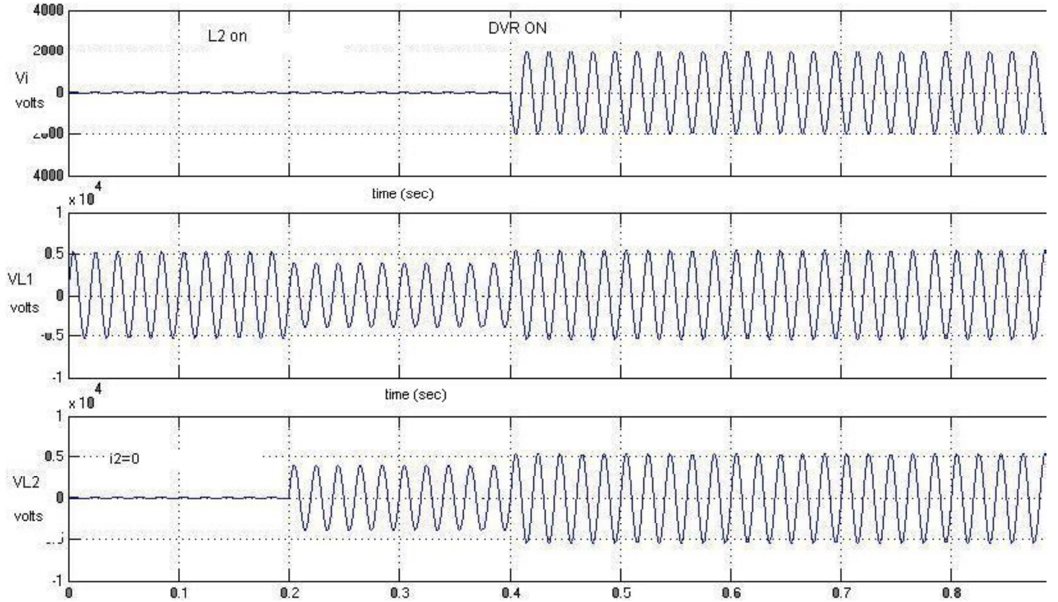

Fig .8 Voltage Across Transformer Primary In External Source and Load1andLoad-2

DVR WITHOUT LC FILTER

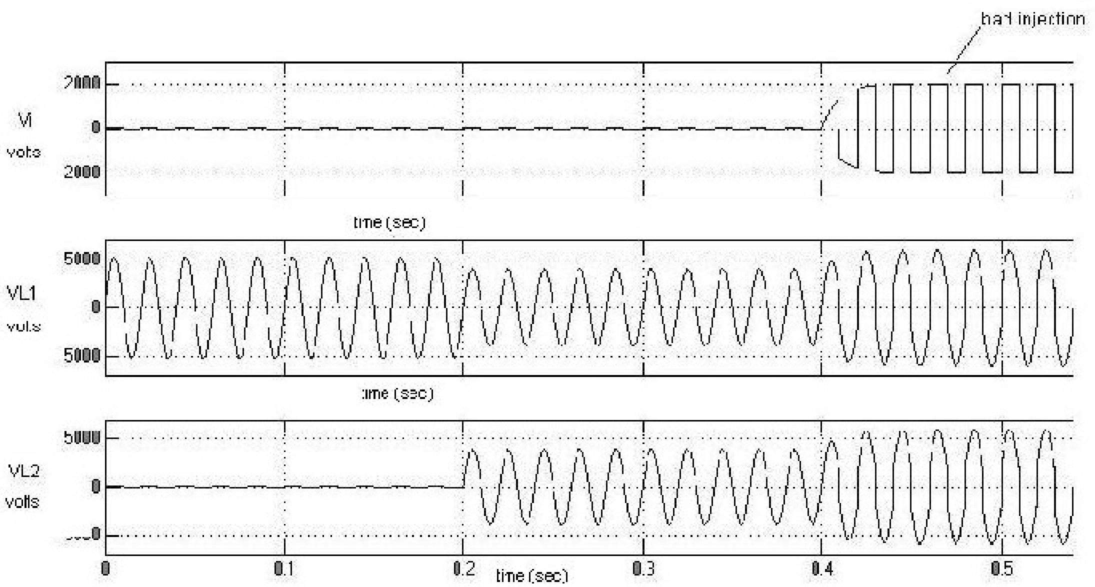

Fig.9 Voltage Across External ,Load1 and Load-2

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DVR WITH LC FILTER

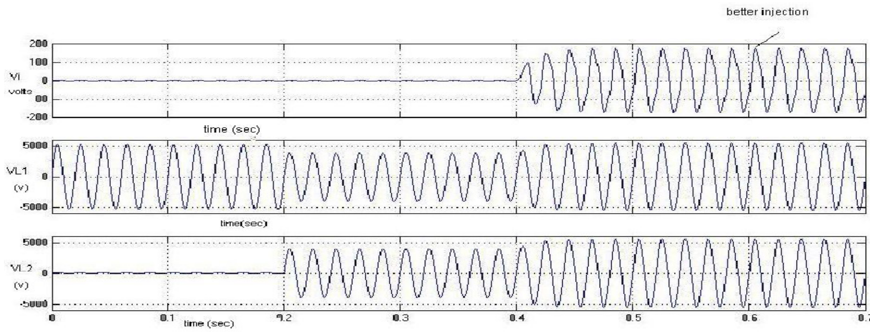

Fig 10 Voltage Across External, Load1 and Load

5. CONCLUSION

This project has presented the Simulation results of"Reduction of Energy Storage Requirements in FutureSmart Grid Using Electric Springs", showing a goodagreement with the theoretical analysis.The wind system, battery system and hybrid system aresuccessfully modeled and simulated. THD is reduced by using LC filter.

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