Control of Voltage and Frequency in Power System using Electric Spring

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Abstract: A novel device for the implementation of dynamic load response, which is known as the electric springs (ES). It has been developed for mitigating both active power and reactive power imbalances. It will providing voltage stability in deregulated renewable energy sources powered grid. Electric spring will providing electric voltage support, damp electrical oscillations and storing the electric energy. It adopts the phase angle and amplitude control which respectively adjust the active power and the reactive power of the system. The major issue concerned with the Electrical energy is about its storage. Electrical power has its own limitations over its storage it can only be generated and consumed at the same instance of time, but during discrepancies in generation and load demand there is a necessity to match both. Variation of active power and reactive power resulting from renewable energy sources will introduce a change in voltage drop along the power line. The voltage variation may cause serious problem for critical loads, which demands a high quality voltage supply. Large deviation between the supply and the demand due to fluctuations in renewable energy sources result in unexpected voltage and frequency fluctuations in system. Electric Springs contributes a fraction of the power change and relies heavily on the series with non-critical load for shaping the power flow.

Index Terms* – *Control, Electric Springs (ES), Frequency, Voltage, Active Power, Reactive Power

I. INTRODUCTION

Power distribution system is a highly critical infrastructure for modern power grid. In recent years, with the large scale integration of intermittent renewable energy generation which causes instability in the power grid, the power quality problems in distribution system have earned widespread attention.

A novel concept of smart load technology termed as Electric Spring (ES) is illustrated and evaluated in the rest parts of this thesis. The ES is able to provide dynamic compensation to maintain the system stability. In order to implement ES in complex distribution networks, a software model of ES is designed in Matlab/Simulink for further research.

Furthermore, after replacing capacitors on the DC link of the ES with batteries, both the active and reactive power compensation can be realized by the ES. Several new control strategies of the ES which offer more functions on power quality improvement are derived. With the help of the ES, the proposed adaptive smart load can damp the voltage oscillation, reduce the frequency variation, and shave the peak demand.

The proposed ES can reduce the three-phase power imbalance and regulate the mains voltage. There are two operating modes for the ES of this version; one has higher priority on voltage regulation, while the other has higher priority on power balancing. This special feature offers more options to system operators. The performance of the proposed ES control strategy is evaluated by applying it in a building model with severe power imbalance and voltage fluctuation.

II. BASIC PRINCIPLE

Analogous to a mechanical spring, an electric spring is an electric device that can be used to: i) provide electric voltage support; ii) store electric energy; and iii) damp electric oscillations. An analogy of the mechanical spring and an electric spring under 3 conditions are illustrated in Fig. 1, in which an electric spring is connected in series with a dissipative electric load Z1. The neutral position of an electric spring is a reference voltage at which the spring is designed to maintain. The series arrangement of the electric spring and Z1 across the ac mains is used to maintain the ac mains voltage Vs to its nominal reference level Vs_ref, which is considered as the neutral position. Similar to the mechanical spring that can develop mechanical force in either direction when the displacement is changed from the neutral position, an electric spring can provide voltage boosting and voltage reduction functions as illustrated in Fig. 1.

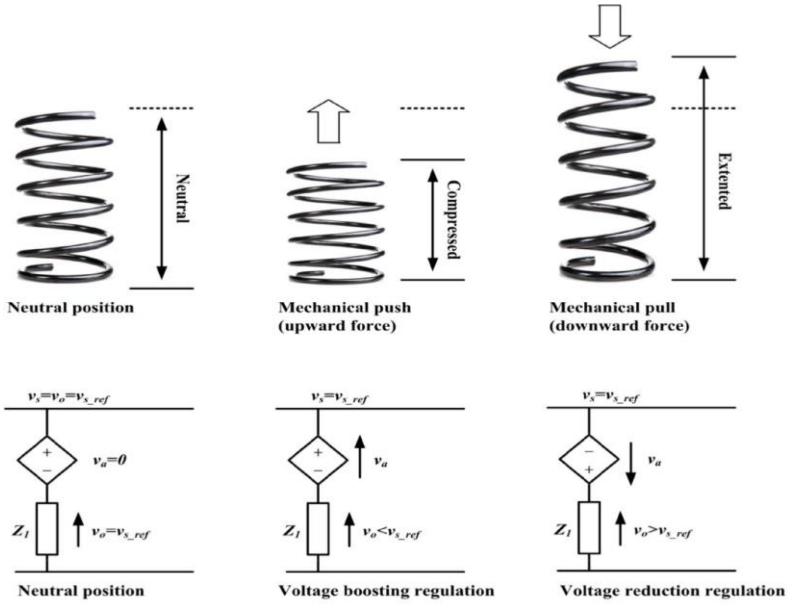

Fig.1. Analogy of a mechanical spring and an electric spring

III. SYSTEM CONFIGURATION

A. ES Configuration

Borrowing the concept of the mechanical spring, the ES has the following functions: 1) provide the electric voltage support; 2) store electric energy; and 3) damp electric oscillations. The configuration of an ES is shown in Fig. 2. The output of the ES is serially connected to a noncritical load to form a smart load. The noncritical load can be a single or a group of electric loads which can tolerate some degrees of voltage variation without causing significant inconvenience to the user.

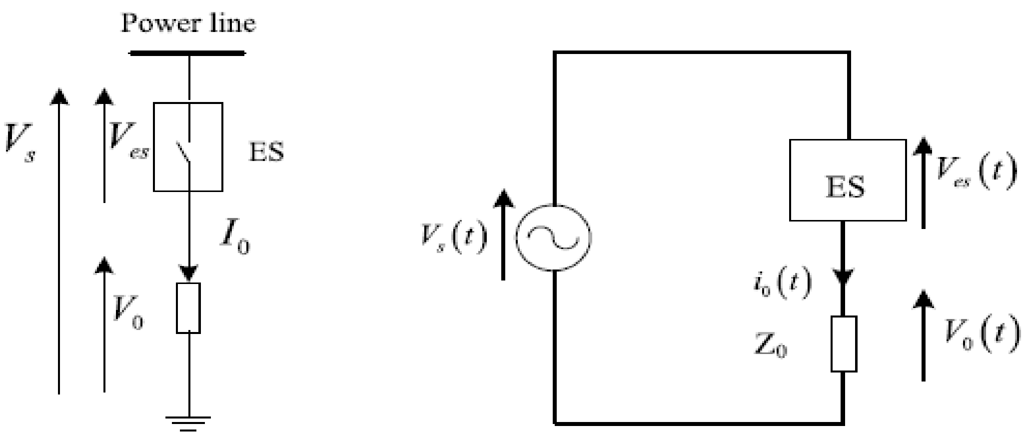

Fig.2. Configuration of an ES

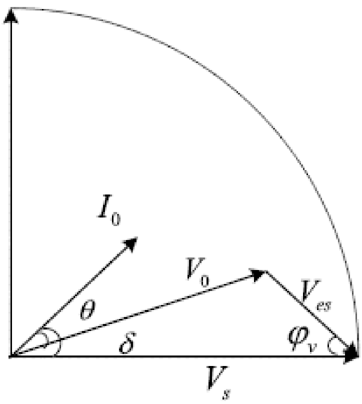

Fig. 3. Phasor diagram of ES.

B. Operational Principle

The vectorial sum of the noncritical load voltage Vo and the compensation voltage Ves is equal to the supply voltage Vs. Vo can be boosted or suppressed by Ves which is generated by the ES. Consequently, the power consumption of the noncritical load can be controlled. Fig. 3 shows a phasor diagram of the operation mode of which ES provides the voltage boost function. The ES acts as a series compensator which could provide a variable ac voltage that changes the voltage of the load Z0, thus changing the power flowing to the load even though the line voltage Vs and the load Z0 are unchanged. The ES can, in principle, perform active and/or reactive power control. For instance, the change of compensation voltage Ves can simultaneously provide reactive power compensation to the power system when the voltage Ves is controlled in quadrature with the load current Io. Meanwhile, the active power consumption can be performed when a battery is equipped at the dc side. As far as the charging and discharging of the battery is concerned, during the normal condition, this problem could be avoided. It is assumed that the battery operates in an ideal mode and has good charge/discharge characteristics in this paper. Actually, the batteries can be replaced by other types of bidirectional dc voltage source or a dc/ac bidirectional power converter of which the ac side is connected to the power grid.

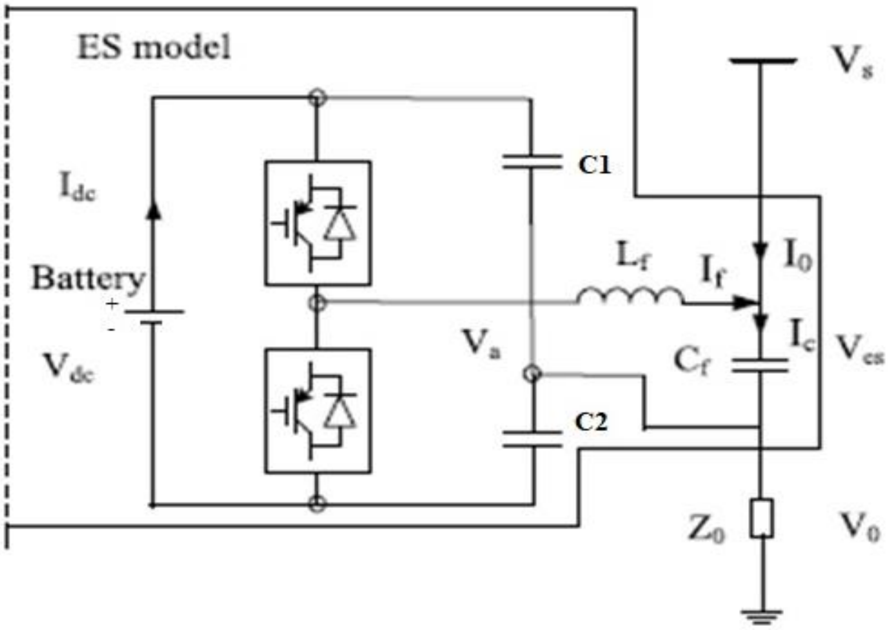

Fig.4. Circuit diagram of the ES

IV. CONTROL STRATEGY

Power The ES may be implemented using a half-bridge single-phase inverter with an inductor capacitor (LC) output filter for eliminating the high-frequency pulse width modulation (PWM) signal as shown in Fig. 4. The protection of the capacitor in this configuration should be considered with the elaborate design of LC filter. The ES output is connected in series with the grid and also to the load and it can produce either an active (±Pes) and/or reactive power (±jQes) difference between the power source and the load. At steady state, the power relationship between the grid, the load and the ES could be obtained as follows:

$$P_s = P_o \pm P_{es}$$
$$Q_s = Q_o \pm Q_{es}$$

The ES power, the load power and the power source are expressed below,

$$P_{es} = |V_{es}| \times |I_o| \cos(\delta + \varphi_v)$$
$$Q_{es} = |V_{es}| \times |I_o| \sin(\delta + \varphi_v)$$
$$P_o = |V_o| \times |I_o| cos\theta$$
$$Q_o = |V_o| \times |I_o| sin\theta$$
$$P_s = |V_s| \times |I_s| cos\delta$$
$$Q_s = |V_s| \times |I_s| sin\delta$$

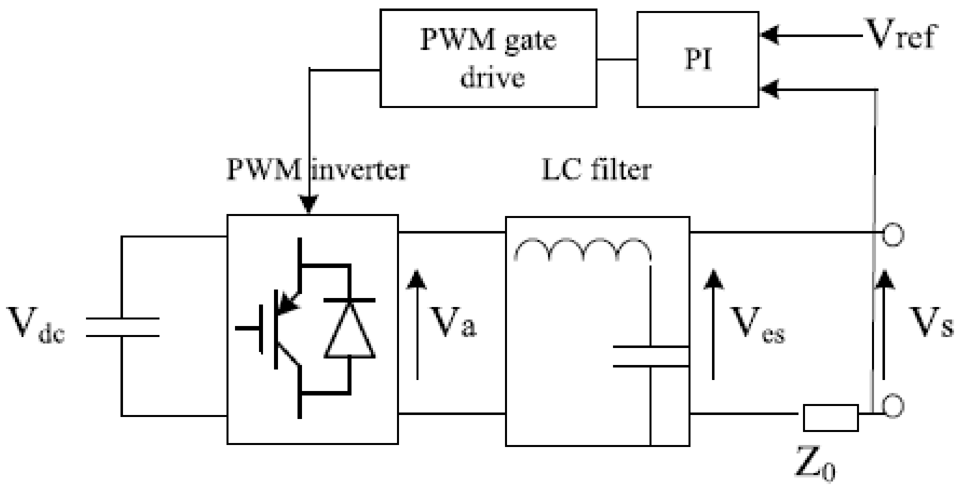

Fig. 5 ES with voltage control loop

As illustrated in Fig. 5, by controlling the *m* of the PWM inverter, high quality PWM voltage waveform at the line frequency can be generated. With the use of the low-pass filter, a sinusoidal voltage (*V*es) with the controllable magnitude by adjusting the *m* obtained from the ac voltage controller can be generated as the output of the LC filter. The reactive power may be directly controlled by varying the amplitude of the compensation voltage *V*es across the filter capacitor of the ES.

V. Practical Evolution of the ES

Fig.5 shows the practical setup of the first test. Using the input voltage control method, the voltage error is fed to a compensation controller which generates the magnitude control signal for the sinusoidal PWM generator. Via a synchronization network, a phase control signal is also fed to the sinusoidal PWM generator, which in turn provides the gating signals for the power inverter. The PWM voltage output of the inverter is filtered by the low-pass LC filter so that the electric spring voltage is sinusoidal. The phase control signal ensures that the electric spring current is either leading or lagging the electric spring voltage by 90.

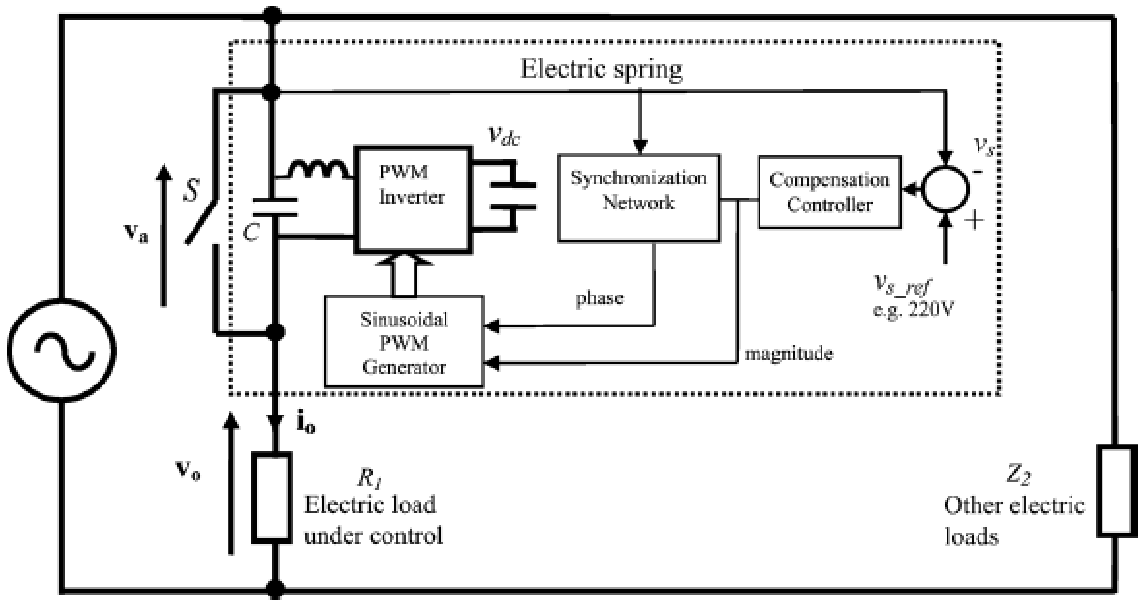

Fig 6 The experimental setup for the electric spring (with control block diagram)

When the electric spring (ES) is operated near the neutral position, the measured waveforms of the mains voltage (Vs), noncritical load voltage (Vo), the ES voltage (Va), and the ES current (same as the noncritical load current) are recorded and shown in Fig. 6. In this case, Va is essentially equal to Vs as the Va is only 4 V rms for a 220 V mains. Fig. 6 shows the corresponding waveforms when the ES is operated in the capacitive mode. It can be observed that the ES current leads ES voltage. Here negative reactive power is provided by the ES and Vo is smaller than. Then the ES is operated in the inductive mode and the corresponding waveforms are shown in Fig. 6. It can be seen that the ES current can be controlled to lag the ES voltage. Under the inductive mode, the ES injects positive reactive power into the system to provide voltage support.

VI. CONCLUSION

In this paper, a simple decoupling control scheme is proposed for the power flow control of ES in a microgrid with variable and uncertain renewable. The proposed strategy could realize the active power and reactive power control of ES by adjusting the shift angle and the amplitude of the modulation signal. When connected to the load in series, the ES provides the voltage support to prevent the voltage dip on the bus it is installed, and the bus voltage could be tightly regulated at a given deviation during transients. In addition, the frequency nadir could be enhanced for the sake of the active power contributed by ES. Thus the steady-state frequency deviation could be further improved. When ES is installed on the different bus with the disturbance source, the problems concerned with the frequency in the microgrid could still be mitigated effectively. It has been explored that ES could be a potential key component in the future smart grid with substantial renewable energy sources.

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