Journal of Engineering Sciences
Vol 11, Issue 2, FEB /2020
ISSN NO:0377-9254

ELECTRIC SPRING FOR IMPROVE ACTIVE AND REACTIVE POWER COMPENSATION AT LOAD SIDE

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Abstract:

Electric spring has a lot of advantages like simple control and without needing a lot of energy storage, which is applied to the load side by means of suppressing voltage fluctuation caused by the reactive power fluctuation. The simulation model with electric spring is built by using the software of Matlab/Simulink. Through observing the changed voltage waveform on power grids with or without electric spring, the simulation results show that the electric springs are capable of regulating voltage at the load side.

1.INTRODUCTION

Centralized control is adopted in the existing power system where power generation mainly depends on the load prediction. Nowadays, with the increasing portion of power generated from the renewable energy sources (RESs) and injected into the power system, stability issues become more and more severe due to the RES intermittency Flexible alternating current transmission systems are used to control voltage and/or power flow. However, most of them are suitable for high- or medium-voltage applications, and cannot be used for future low-voltage micro grids with high RES penetration, such as roof photovoltaic (PV) and small power-rating wind plants. To cope with this need, the electric spring (ES) technology has been proposed for future distributed micro grids to transfer the line voltage fluctuations to the so-called non-critical loads (NCLs), i.e. to the loads that tolerate a large supply voltage range, so as to keep regulated the voltage across the so-called critical loads (CLs), i.e. the loads that tolerate a narrow supply voltage range. The transfer occurs through an automatic balance of the load demand with the power generation, performed by ES. The set made of ES and NCLs forms the so-called smart load (SL). The voltage across CLs and the in-parallel SL is hereafter designated with grid voltage. So far, many papers have appeared reporting on ES topologies [8] and their control strategies. The first version (ES-1) in can only manage the reactive power whilst the second version (ES-2) in can manage both the active and the reactive power as the capacitor in the DC side of ES is replaced by a voltage source like a battery pack. The third version (ES-3) in is a new type of ES without NCL. The so-sequenced fourth version (ES-4) in changes the performance of ES greatly, since it compels the NCL voltage to vary in the same manner as the line voltage by the help of the insertion of an additional transformer in the original ES-2. Previous works have reported various control schemes of the ES-2. For instance, proposes the control of the input current by resorting to the dq0-transformation. This solution, however, is unable to keep unaltered the grid voltage as it is regulated in an open-loop mode. Even if a closed-loop with a proportional integral (PI) regulator is added to regulate the grid voltage, it mainly takes care of the power factor correction rather than of the voltage regulation. In, the δ control is proposed to adjust the instantaneous phase of CL voltage but relies on system modeling that utilizes the circuitry parameters. Recently, the radial-chordal decomposition (RCD) control is proposed in to decouple the control of the power angle of SL from the voltage across CL, which makes ES-2 ready to be embedded in many devices such as water heaters. However, it still has some shortcomings. For instance, the power angle of NCL should be known in advance, which prevents the use of the RCD control when NCL varies or is non-linear. Besides, it is difficult to obtain pure reactive power compensation by means of ES. Power control of ES-2 is studied in this paper with reference to a practical application. Let us consider a low power outdoor wind power plant as an example the maximum power point tracking (MPPT) technique is normally adopted in the wind and/or solar power generation plants. The tracked active power is consumed by the electrical loads at domestic homes, which are of both CL and NCL types. For an ES installed at the same location as the wind power plant, the active and reactive powers generated by the plant can be measured by ES even if they are changing quickly. As a result, ES in such situation can carry out the control of both the input active and reactive power and, by the latter control, can regulate the RMS value of the CL voltage at the pre-set value. Although constant active power compensation can be achieved by the δ control in, its shortcomings

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ISSN NO:0377-9254

cannot still be overcome. Instead, the RCD control in can regulate the grid voltage and can also correct the power factor of SL by the independent radial and chordal actions. However, does not discuss the situation in which the input active power is constant. Even if one can demonstrate that the RCD control can deal with such a situation, calculations necessary to determine the reactive power that ES must provide are very involved, especially during the transients. Aiming at the massive applications of ES-2 in the distributed power systems, this paper proposes a simple active and reactive power control as a solution to the shortcomings of the existing control methods. The proposed control not only decouples the active and reactive powers, but also relies on a local signal manipulation that does not need any information on the ES-2 circuitry parameters and the line voltage and parameters. Besides simulations, experiments are accomplished in three steps to verify the power management capabilities of the ES-2 implementing the proposed control.

2. ELECTRICAL SPRING

A recently proposed concept of "electric springs" that can be integrated into electrical appliances to become a new generation of smart loads. The electric spring is capable of providing different types of power/voltage compensations to the load and the source.

For reactive power control, an electric spring (ES) injects a compensation voltage VES in quadrature with the current through it. The current Io can either lead the voltage VES by 90o (capacitive mode for voltage support) or lag VES by 90º (inductive mode for voltage suppression). The power converter circuit of the ES could simply be a two-level inverter

By regulating the input voltage Vs and letting the output voltage Vo to fluctuate dynamically (i.e. a new input -voltage control), an ES would (i) provide voltage support and (ii) simultaneously modulate the non- critical load power to follow the power generated. Such a subtle change in the control strategy of a traditional RPC from output control to input control offers new possibility of simultaneous voltage and frequency control enabling effective demand side management

This control technique is achieved by phase shifting the input signal (voltage/current) by π/2.The overall action of the L power filter to eliminate the harmonics created by a non-linear load on the source side.

The proposed electric spring is connected in series with the noncritical loads to form a new generation of smart loads. A control scheme for such smart loads to reduce power imbalance within the building's electric power system has been evaluated. The results have confirmed the effectiveness of the new three-phase electric springs in reducing power imbalance and voltage fluctuation, making the building loads adaptive to internal load changes and external mains voltage changes. The use of the electric springs in reducing energy storage requirements in power grid. Unlike traditional 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. δ control is the key concept in this paper, which is realized by controlling the phase angle of the predefined reference in a proportional resonant controller. Four critical operating functions of the ESs are analyzed with different critical loads such as resistive, inductive and capacitive types, where vector diagrams and geometric relationships are explored for δ calculation with which the ac mains voltage is regulated to the predefined value and the phase angle between the ES voltage and current is determined. With the proposed δ control, the operating modes of the ES can also be determined automatically as the input voltage varies.

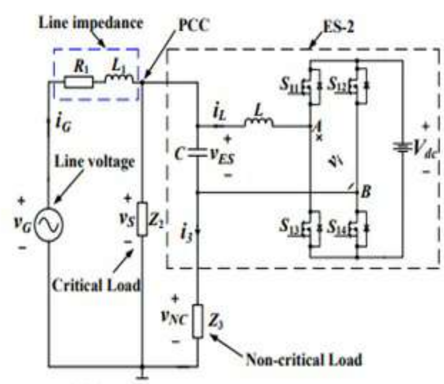

Fig.2.1. Topology of ES-2 and Associate Circuitry

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ISSN NO:0377-9254

3.OPERATION OF ES-2

3.1 ES-2 Topology

As explained in , electric loads are divided into two types, namely CLs and NCLs. ES is an electrical device that is able to regulate the CL voltage at a pre-set value while passing the voltage (and power) fluctuations from the sources to NCL.

The topology of ES-2 and the associated circuitry are drawn in Fig.1. In this figure, ES-2 is enclosed by the dashed line and consists of a single-phase voltage source inverter (VSI), an L filter and a capacitor whose voltage sums up to that of the NCL. Moreover, Z2 is the CL, Z3 is the NCL, vG represents the line voltage of the power system with RESs, R1 and L1 are the line resistance and inductance, respectively. The branch including vG and the line impedance supplies CL and SL. vS denotes the voltage of point of common coupling (PCC), which is also the CL voltage.

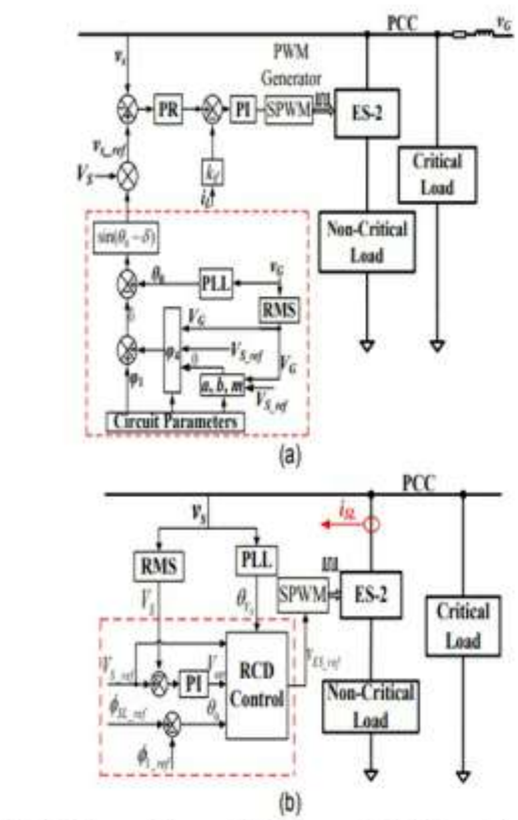

Fig.3.1.ES-2 control diagrams for (a) δ control, (b) RCD control.

3.2 The Proposed Power Control

In this section, the proposed power control is presented, explaining its ability to achieve a simple active and reactive power control for ES-2 by a local signal manipulation. In the proposed control, the single-phase dq rotating frame is adopted. By looking from PCC to the right side in Fig.3.1, active, reactive and apparent powers can be expressed from (3) to (4), where Pin and Qin are the total active and reactive power absorbed by ES, CL and NCL together, respectively.

3.3Power Control of ES-2

The control diagram of the proposed simple power control is shown in the block of Fig. 4.2(a) enclosed by the dashed line. The control calls for the detection of variables such as the input current i1 and the CL voltage vS. The input active and reactive powers of the ES system, marked as Pin and Qin, are obtained by manipulating the instantaneous values of vS and i1 as illustrated by the scheme of Fig. 3.2(b), of which the function block already exists in the Matlab/Simulink. According to Fig. 3.2(a), the RMS value and the instantaneous phase of the CL voltage are detected by the RMS and PLL blocks, respectively. The powers Pin and Qin are controlled by separate PI regulators. Specifically, the regulator in the d-axis controls Pin and that one in the q-axis control Qin. Alternatively, if the control objective is the CL voltage instead of Qin, a loop outer the q-axis is added closed with a PI regulator, and its output represents the reference for Qin, designated as Qinref. The output signals of the PI regulators in both the loops are processed through the inverse dq-to-αβ transformation to get the modulation signal vcomp1. It should be noticed that functionality of harmonic suppression is added in Fig.3.2 (a) by subtracting the harmonic component denoted as vS_h from vcomp1. The drive signals for the VSI transistors are obtained by the SPWM technique, just after a limiter.

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ISSN NO:0377-9254

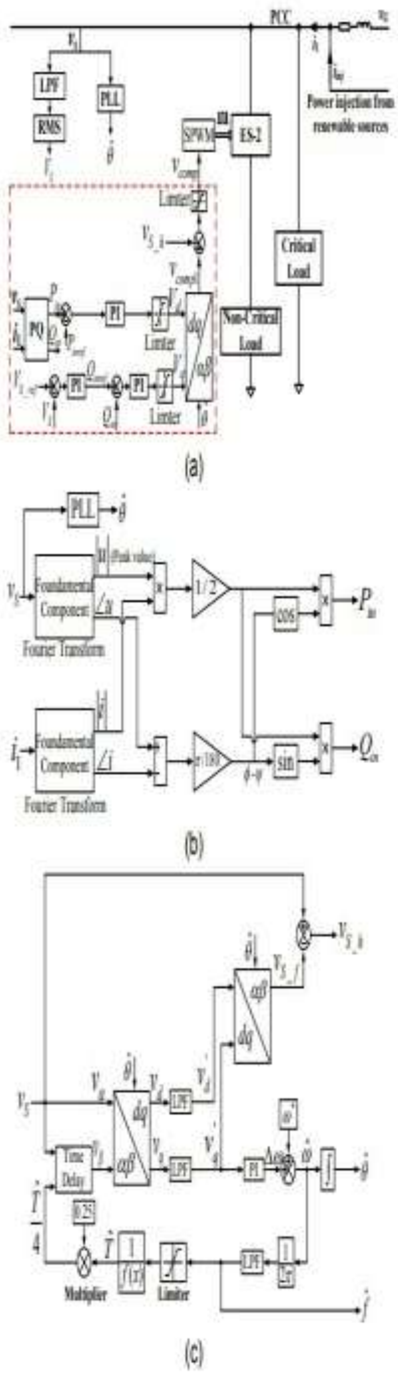

Fig.3.2.The proposed power control of ES-2. (a) Control diagram. (b) Calculation diagram of active and reactive power. (c) Functions of PLL and harmonic extraction.

To simplify the analysis, both CL and NCL are chosen of resistive types. It should be noticed that they can be any other linear types. For the ES-2 system under simulation, the control objectives are formulated as follows: i) RMS value of the PCC voltage or input reactive power is regulated at a pre-set values, and ii) input active power Pin tracks the pre-set value Pinref. Three situations are investigated, namely Pinref varies at fixed VG. VG varies at fixed Pinref Distorted VG.

4. MATLAB SIMULATION RESULTS

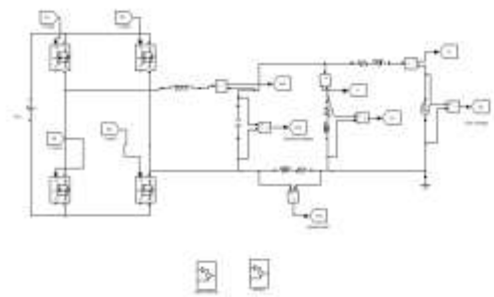

Fig 4.1 simulink model of proposed system

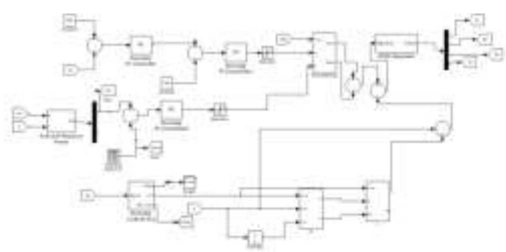

Fig 4.2 control diagram

However, when Pinref drops to 2kW, the active powers of ES and NCL are around -420W and 1.31kW, which means that ES-2 is providing active power. The results also reveal that active powers of both ES and NCL vary in the same way as that of Pin. Therefore, ES not only acts as a power manager that passes the power fluctuations from input voltage sources to NCL, but also acts as an energy storage device that absorbs and/or provides powers.

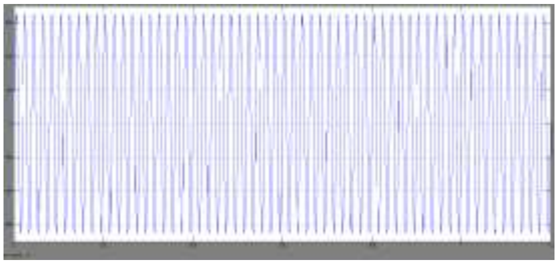

Fig 4.3 Grid Voltage(Vg)

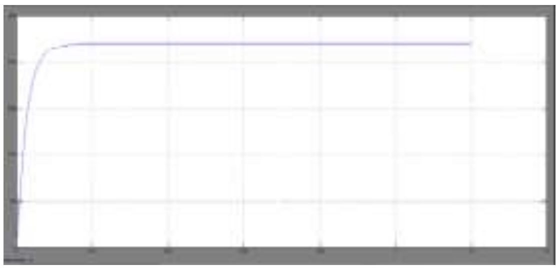

Fig 4.4 Source voltage(Vs)

Fig 4.4 Pin Reference

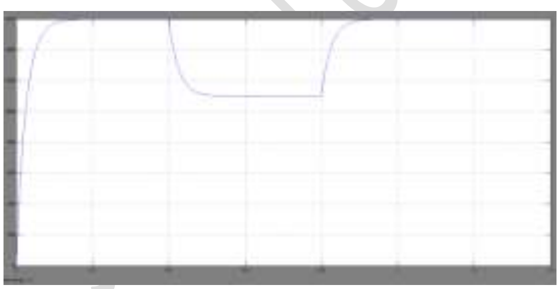

Fig 4.6 Active power

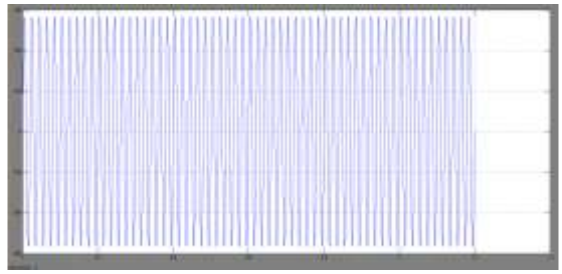

Fig 4.7 grid voltage

Fig 4.8 Source voltage

Fig 4.9 Pin Reference

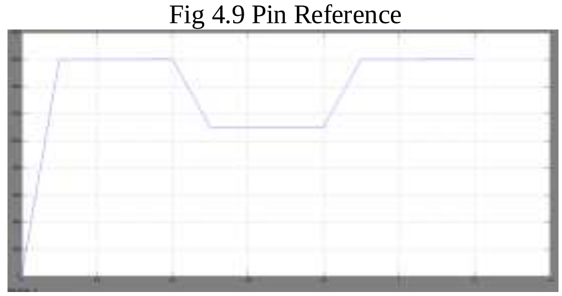

Fig 4.10 Pin

5.CONCLUSION

The input active and reactive power control is proposed for the purpose of practical application of ES-2 in this paper. An overall review and analysis have been done on the existing control strategies such as δ control and RCD control, revealing that the essences of the controls on ES-2 are to control the input active power and reactive power. If being equipped together with the distributed generation from RESs, the ES-2 can manage the fluctuated power and make sure the

ISSN NO:0377-9254

controllable power to grid, which means that the ES-2 is able to deal with the active power captured by MPPT algorithm. Simulations have been done on the steady and transient analysis and also under the grid anomalies, validating the effectiveness of the proposed control. Three steps have been set in the experiments to verify the three typical situations and namely the active power generated by the GCC from RESs are, 1) more than; 2) less than; 3) the same as the load demand. Tested results have validated the proposed control

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