POWER QUALITY IMPROVEMENT IN SMART GRIDS WITH ELECTRIC SPRINGS

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***Abstract*— Electric spring (ES), a new smart grid technology, has earlier been used for providing voltage and power stability in a weakly regulated/ stand-alone renewable energy source powered grid. It has been proposed as a demand-side management technique to provide voltage and power regulation. In this paper, a new control scheme is presented for the implementation of the ES, in conjunction with non critical building loads like electric heaters, refrigerators, and central air conditioning system. This control scheme would be able to provide power factor correction of the system, voltage support, and power balance for the critical loads, such as the building's security system, in addition to the existing characteristics of ES of voltage and power stability. The proposed control scheme is compared with original ES's control scheme where only reactive power is injected. The improvised control scheme opens new avenues for the utilization of the ES to a greater extent by providing voltage and power stability and enhancing the power quality in the renewable energy powered micro grids.**

***Keywords*—** Demand-side management (DSM), electric spring (ES), power quality, renewable energy.

I. INTRODUCTION

The first part is the generation system, in which the electricity is produced from large power plants owned by power companies or independent suppliers. Since the voltage level of the generated power follows the rated voltage setting of generators, in order to transmit the power over long distance with minimum power loss step-up transformers are utilized to increase the voltage. The second part is the transmission system, the function of transmission system is to deliver the power from generation system to load center via cables or overhead transmission lines. In order to reduce power loss, the power transmitted is at extra high voltage level in both transmission network and sub transmission network. The third part is the distribution system. The power voltage is firstly decreased to medium voltage (MV) level by step-down transformers at terminal substations. Then the power is transmitted by distribution lines or cables to local substations after its voltage is further reduced to consumer level. At this stage, the electricity can be directly delivered to residential customers, commercial establishments and industry segments. In order to acquire a better understanding of the physical arrangement of the power system, a typical system which supplies electricity to a big city is taken as an example. In generation stage, the power plants are usually located far away from the urban area to avoid pollution. In transmission stage, the transmission lines or underground cables are used to transmit electricity from the power stations to terminal substations [1-8].

In power distribution system, various uncertainties tend to undermine its stability and complicate its regulation. The power quality problems are caused by both the power utilities and the customers. In modern distribution systems, it is impossible to make the system fully controllable due to the unpredictability on either the power supply side or the power demand side. On the supply side, besides the nature factors and inappropriate design of the networks, unpredictable intermittent power generation caused by the integration of renewable energy generation becomes a new uncertainty. On demand side, it is difficult to forecast the customers' behavior accurately [9-15]. Thus, those unpredictable actions of loads can affect the power quality of power grid.

The concept of ES can be extended further to improve the power factor in a renewable energy powered micro grid. Since the ES is implemented through an inverter and by utilizing its potential for both active and reactive power compensation this could be achieved. The real power compensation has been utilized to improve power balance in a three-phase system and to improve the power factor without any voltage or power regulation. The RCD control and Novel control are some of the control techniques to incorporate power factor correction. Electrical parameters of the system and grid voltage (input voltage) are required to implement the control scheme and the control strategy won't be a demand-side solution. Control scheme decouples grid voltage regulation and PFC of the ES-associated smart load [16-23]. We demonstrate implementation of the electric spring through an improvised control scheme to provide the power and voltage stability and overall power factor correction.

II. CONCEPT OF ELECTRIC SPRING (ES)

Similar to the mechanical spring, an ES is an electronic device based on the adaptation of Hooke's law into electrical engineering. The main functions of ES are listed as follow:

• It provides electric voltage support;

• It stores electric energy;
• It can help to damp the electric oscillation.

By controlling the current flowing through the capacitor, the charging and discharging states of the capacitor determine the operation of the ES. Therefore, the ES can be depicted as a current-controlled voltage source which is shown in figure. It further shows the comparison between a mechanical spring and an ES under three operation modes.

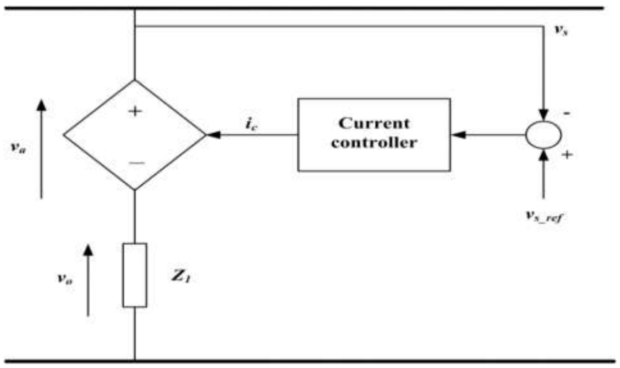

Fig: 1. General control scheme of the ES.

From figure, it can be observed that the ES is series connected with a dissipative electric load *Z1*. This series branch of the ES and *Z1* attached to the main bus can stabilize the ac mains voltage *vs* at its nominal reference value *vs_ref* which is typically 220 V or 240 V. The operation and function of the dissipative load can be summarized as follow: When ES voltage is dynamically varied; the voltage across the dissipative load is deliberately boosted up or suppressed down. This bouncing operation of load voltage can change the power consumption of the load to follow the generation profile. In conventional power grid, it is the power supply that is carefully controlled to maintain the balance between power generation and consumption.

The system operators decide on the power production for each time interval by the unit commitment and the economic dispatch. However, this operation policy is no longer sufficient in future power systems, since the integration of renewable energy sources makes generation highly unpredictable. This new uncertainty on supply side makes it extremely hard to maintain the balance between the power supply and the power demand. To cope with this new challenge in future smart grid, loads on the demand side must operate in a smart way to adapt themselves to the fluctuating generation. This concept of smart load gives birth to a new operation policy that consumption follows generation to main instantaneous power balance in future smart grid. The combination of ES and dissipative load is so far an ideal candidate of smart load. It can provide support for power grid, just as mechanical spring gives suspension support for mechanical appliances such as vehicles and mattresses. Figure shows a typical implementation of an ES in a distribution network. The power supply is consisted of two parts: a stable power source and an unstable wind power source. The capacity of the wind power source is deliberately set to be large enough to cause apparent mains voltage fluctuation, so that the effect of the intermittent nature of wind power on power grid can be simulated. The loads on demand side are categorized into two groups:

• Non-critical load is dissipative load that has a high tolerance on voltage instability. It is connected in series with the ES to absorb fluctuating power generated by wind power source. Examples of non-critical load include refrigerators, lighting systems in underground area;

• Critical load is load that has a high requirement on power quality in terms of frequency and voltage stability. It is connected in parallel with the branch of ES and non-critical load. Examples include computers, elevators, and medical equipment.

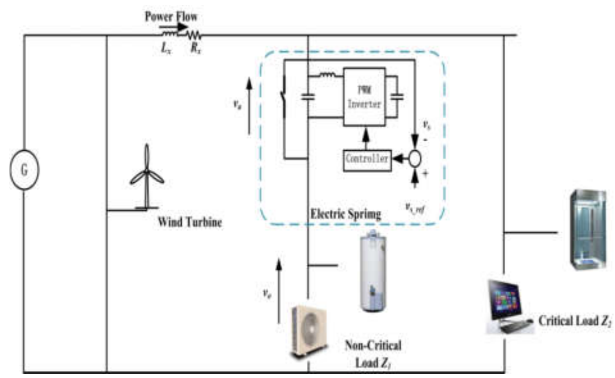

Fig: 2. System configuration of an electric power distribution system with an ES.

The ES operates as a special version of series reactive power compensator. During previous decades, the power electronics based reactive power controllers (RPC) have been developed in power industries to regulate the power flow in transmission system with HV levels. The concept of ES was introduced by drawing parallels to a traditional mechanical spring. In an RES powered micro grid, it could be realized through an inverter and is attached in series with the noncritical load, such as electric heaters, refrigerators, and air conditioners, as shown in Figure 2, to form a smart load. In parallel to this smart load, critical loads like a building's security system are connected. Earlier versions of ES implemented an input-voltage control scheme to generate reactive power compensation in order to provide voltage and power regulation to critical loads in steady state. As a result, the noncritical load voltage and power vary in accordance with the fluctuations in the weakly regulated grid due to intermittent power from RESs. In order to provide only reactive power compensation from the ES, the compensation voltage, i.e., ES voltage, Ves should be perpendicular to noncritical load current, Inc. The ES voltage is governed where Vs is line voltage, Vnc is the noncritical load voltage, and Ves is ES voltage.

III. SIMULATION RESULTS

The system shown in Fig. 1 is considered. It was simulated on a MATLAB/ Simulink platform. The reference line voltage is set to be 230 V (RMS). The system has an effective resistive inductive load, and thus, a lagging power factor.

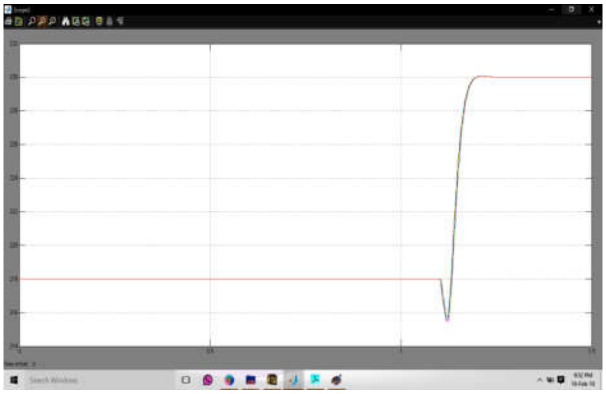

Fig: 3(a) V_{line}

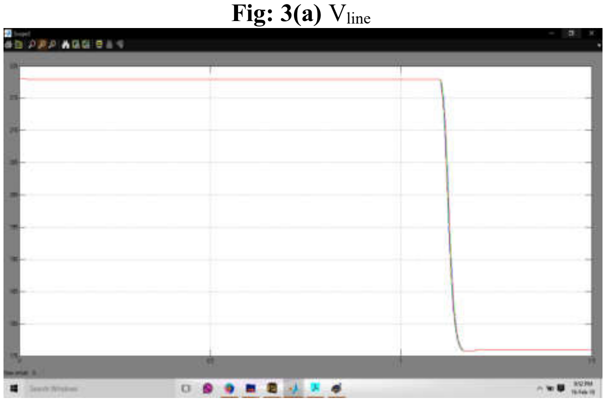

Fig: 3(b) Ves1

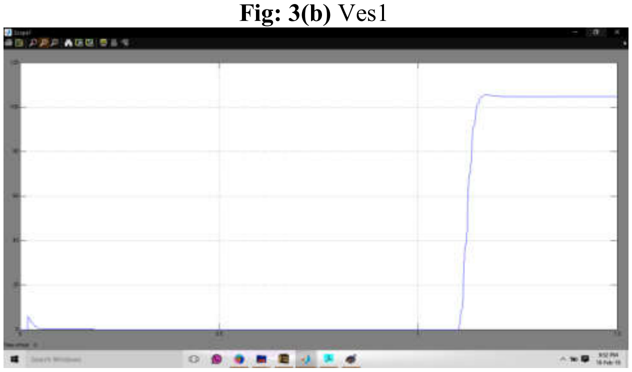

Fig: 3(c) Ves

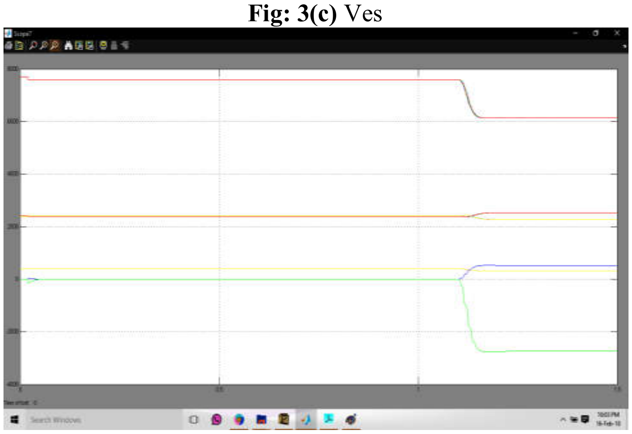

Fig: 3(d) Active and reactive power

The improvised ES, with the proposed control scheme, is subjected to similar scenarios as the conventional ES. This ES would be able to inject both real and reactive power in the system. Similar to the previous subsection, the RMS line voltage is kept at 238 V in overvoltage scenario and the ES is turned ON at t = 0.5 s. The ES reduces the line voltage to the reference value of 230 V shown in Fig. 3. It injects real power (Pes) of 1500 W and 1500 inductive VAR (Qes) in the system (see Fig. 3). The power factor of the system reduces from 0.965 (lagging) to 0.93 (lagging) as shown in Fig. 3. To maintain the line voltage to the reference value of 230 V, the ES injects a combination of real and inductive power in a highly inductive system, thus, the power factor is reduced from 0.965 to 0.93. However, the conventional ES worsens the power factor from 0.965 to 0.895. Though the performance with the improvised ES is not an optimal unity power factor, it is better than the conventional ES, which worsens the system power factor in the over voltage scenario; a 1.5% improvement in the power factor is observed with the proposed control scheme as compared to the conventional ES.

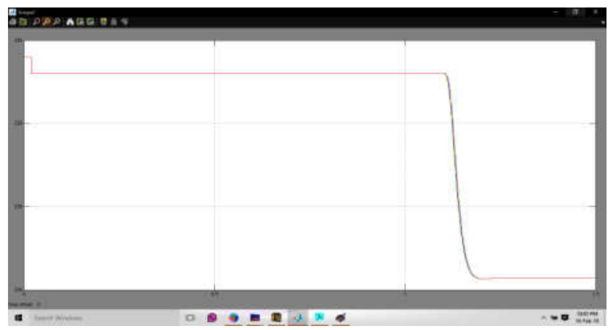

Fig: 4(a) Vline

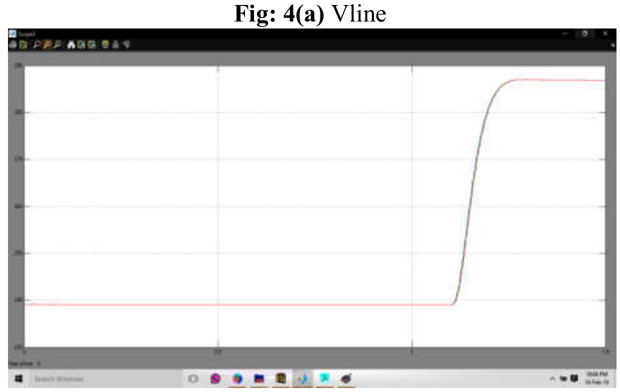

Fig: 4(b) Ves1

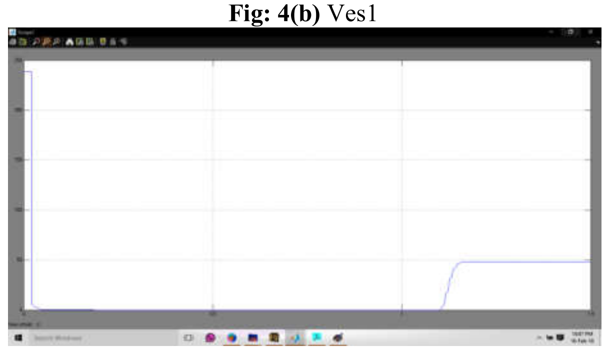

Fig: 4(c) Ves

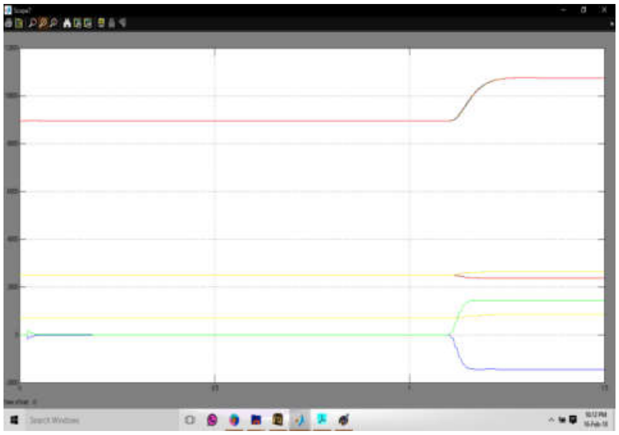

Fig: 4(d) Active and reactive power

In the under voltage scenario, the ES boosts the RMS line voltage from 218 to 230 V when it is turned ON at t = 0.5 s as shown in Fig. 15 The ES absorbs 1100 W (Pes) and injects reactive power (Qes) −2750 VAR (i.e., capacitive VAR) in the system as depicted in Fig. 4. The power factor of the system improves from 0.965 (lagging) to almost unity (see Fig. 4). The voltage and power consumption of the noncritical load are reduced as visible. In the overvoltage scenario, a 4% improvement in the power factor from the conventional ES is observed. The conventional ES injects only inductive power in the system, whereas the improvised ES injects both real and inductive power. While in the under voltage scenario, a 1.5% improvement is observed; the conventional ES injects only capacitive power and improvised ES injects both capacitive and real power in the system.

IV. CONCLUSION

In this project, as well as earlier literatures, the ES was demonstrated as an ingenious solution to the problem of voltage and power instability associated with renewable energy powered grids. Further in this project, by the implementation of the proposed improvised control scheme, it was demonstrated that the improvised ES maintained line voltage to reference voltage of 230 V, maintained constant power to the critical load, and improved overall power factor of the system compared with the conventional ES. Also, the proposed "input-voltage – input-current" control scheme is compared to the conventional "input-voltage" control. It was shown, through simulation and HIL emulation that using a single device voltage and power regulation and power quality improvement can be achieved. It was also shown that the improvised control scheme has merit over the conventional ES with only reactive power injection. Also, it is proposed that ES could be embedded in future home appliances. If many noncritical loads in the buildings are equipped with ES, they could provide a reliable and effective solution to voltage and power stability and PFC in a renewable energy powered micro grids. It would be a unique DSM solution, which could be implemented without any reliance on information and communication technologies.

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