Hardware Implementation of Electric Spring Converter in a PV and Wind based Smart grid for Power Quality Improvement

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Abstract

In this paper, an electric Spring based Converter is proposed for the improvement of power quality in a PV and wind based smart grid. Permanent Magnet Synchronous Generator is used for conversion of wind energy into electrical energy. An electric Spring has the characteristic feature of fast recovery of the performance of the electrical system. It modulates the Voltage, frequency, THD of voltage and current. It improves the power factor during abnormal conditions of wind and solar energies. An effective control scheme has been developed with the Back-to-Back inverter to obtain stability in difficult weather conditions also. The prototype of the proposed converter is developed and its performance is verified with the results obtained from the simulation. The result shows that the Electric Spring Back-to-Back converter effectively stabilizes voltage and frequency and the reactive power is compensated.

Keywords. Electric Spring, MPPT, PMSG, Back-to-Back Converter, Smart Grid.

1. INTRODUCTION

A review of recent research works shows the efficient distribution of renewable energy in a smart grid system. In addition to diesel generators, several renewable inputs like photovoltaic (PV) and wind turbine have been regarded for efficient distribution of renewable energy. It is extremely difficult to determine the size of photovoltaic, wind and diesel generators in the efficient distribution of renewable energies. Renewable energy grid integration is difficult because the power factors of voltages and currents change with changing weather conditions. This is mainly due to many factors related to this problem, instability because of renewable resources. Consequently, renewable energy system control strategies are primarily designed to detect maximum power, optimize the management of energy supplies as well as the control of demand voltage and frequency. Therefore, to meet this challenge, a comprehensive smart grid infrastructure is required to offer a workable resolution.

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The ability of a power grid to address current grid difficulties, such as increasing demand for electricity, aging infrastructure and the infiltration of distributed energy sources into supply. With the invention of latest technologies, it is proposed to change the existing power grids to smart grids. Compared to conventional centralized power plants, renewable energy source power generation devices may be located nearer to main grid and they are more compact and economical. Electricity grids are being modernized to a smart grid to improve reliability and to make it easier to integrate renewable energies and to effectively manage energy usage.

2. ELECTRIC SPRING CONVERTER

Electric Spring Converter hardware is designed with two back-to-back converters with a storage battery connected between the Converters as a storage device. A grid supplied by renewable energies may maintain voltage and power stability using the latest electronic grid component known as Electric Spring. A demand side planning strategy to produce voltage and power control has been presented.

The restoring force of an optimum mechanical spring, according to Hooke's law, is inversely proportional to its deviation from the equilibrium point.

$$F = -kx \tag{1}$$

F Restorative force of spring which tries to get its equilibrium position, x displacement from the equilibrium position, k spring constant.

Potential energy which is stored in the mechanical spring given as

$$PE = \frac{1}{2}kx^2 \tag{2}$$

Similar to a physical spring, an electrical spring can sustain the required electrical tension, store electrical power, and dampen electric vibrations brought on by transitory circumstances. The definition of an electric spring is

$$q = C\vartheta_a \text{ inductive mode} \tag{3}$$

$$q = -C\vartheta_a \text{ capacitive mode} \tag{4}$$

$$q = \int i_c \, dt \tag{5}$$

i_c is the current flowing through the capacitor having the electric charge q with a potential difference of ϑ_a.

Here the capacitor's stored electric charge can control the electric spring's voltage regulation function by injecting or by absorbing the voltage. By using a current controlled source, charge through the capacitor can be regulated. Consequently, an electrical spring may be thought of as a supply voltage with control scheme. An electrical spring can regulate amplitude along a maximum stress by linking to non-critical loads in line, as illustrated in Fig. 1. Here the current source is a voltage source with command strength. Just as a mechanical spring develops mechanical force from a neutral position, an electric spring adjusts voltage drop and operates a constant or managed voltage at critical loads.

By adjusting the electrical potential difference across the capacitor via the current source, an electrical spring voltage may be produced. The electrical dock's dynamic voltage support is made possible via closed loop control, which has the ability to change the main supply value in the power grid. The electric spring may also be used for electric noise damper, which linking words another device in series with the electric spring to dissipate the electric charge. As demonstrated in fig. 1, non-critical demands could be linked in serial. The series linked electric load, as shown in the power system difference, wastes electrical power for damper and can be beneficial to manage the tension across the electrical spring to ensure that the electricity usage of non-critical loads varies with the power grid. Hybrid generation systems having wind, PV as generating sources are unstable as these renewable energy sources depend on weather conditions. Due to this, ac voltage across critical loads dynamically changes with power generation of hybrid system. By connecting electric spring with a dissipative non critical load, critical loads which are connected in parallel with power system will get required well-regulated mains voltage.

For improving stability of hybrid system with substantial renewable generation, novel smart load electric spring technology is highly distributed solution. Using this Electric spring technology more diverse control options and wider operating range is achievable. In addition, with voltage support and electric oscillations damping, some other favourable features of this technology are primary frequency control, power quality improvement and power balancing.

A back-to-back converter with Electric Spring (ES) technology is introduced in [9]. Compared with battery storage or capacitor storage, back-to-back converter-based ES technology has an extended range of compensation and independent of battery storages. ES with back-to-back converter consists of one series converter and one shunt converter. Series converter regulates load voltage or frequency and shunt converter maintain stable DC voltage across DC link.

Stabilized DC link voltage of back-to-back converter can instantaneously balance active power flow between shunt and series converters. Individual controlling of both converters is possible because of independent reactive power capacity of both converters. Active and reactive power characteristics of the back-to-back converter can be described as

$$P_{sh\_es} = |V_s||I_{sh\_es}| \cos\theta \tag{6}$$

$$P_{se\_es} = |V_{se\_es}||I_{ns}| \cos\alpha \tag{7}$$

$$P_{sh\_es} = P_{se\_es} \tag{8}$$

$$Q_{sh\_es} = |V_s||I_{sh\_es}| \sin\theta \tag{9}$$

$$Q_{se\_es} = |V_{se\_es}||I_{ns}| \sin\alpha \tag{10}$$

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$|V_s|$, $|V_{se\_es}|$, $|I_{ns}|$, $|I_{sh\_es}|$ are the RMS values of mains voltage, series converter voltage, non-critical load current and converter shunt current respectively, θ is the phase difference between mains voltage and shunt converter current, α is the phase difference between non critical load current and series converter voltage

The shunt converter current and the series converter voltage must be within the operating range of the rear converter. The maximum amount of reactive power must be delivered by both converters during any serious voltage sag to keep the voltage constant at the critical load. In addition, the shunt converter must also maintain a constant voltage on the DC link.

The symbol for non-critical grid voltage is

$$|V_{nc}| = \sqrt{|V_{se\_es}|^2 + |V_s|^2 - 2|V_s||V_{se\_es}|\cos(\theta_{se\_es})} \tag{11}$$

$$\theta_{Vnc} = \cos^{-1}\left(\frac{|V_s| - |V_{se\_es}|\cos(\theta_{se\_es})}{|V_{nc}|}\right) \tag{12}$$

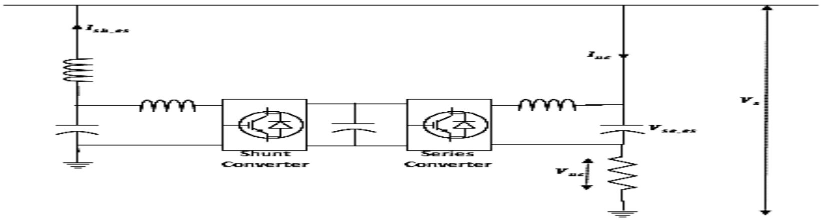

Fig. 1. Back-to-back converter for an electrified spring

For non-critical demand, assuming constant impedance it is possible to write its current as

$$I_{nc} = \frac{|V_{nc}|}{|Z_{nc}|}\angle(\theta_{Vnc} + \cos^{-1}(pf)) \tag{13}$$

The actual and reactive energy of a series converter may be calculated based.

$$P_{se\_es} = |V_{se\_es}||I_{nc}|\cos\alpha \tag{14}$$

$$Q_{se\_es} = |V_{se\_es}||I_{nc}|\sin\alpha \tag{15}$$

$$\alpha = \theta_{se\_es} + \theta_{Vnc} - \cos^{-1}(pf) \tag{16}$$

Real and reactive power for Shunt converter's can be derived as

$$P_{sh\_es} = P_{se\_es} \tag{17}$$

$$Q_{sh\_es} = |V_s|\sqrt{I_{sh\_eslim}^2 - \left(\frac{P_{sh\_es}}{|V_s|}\right)^2} \tag{18}$$

Back-to-back converter, Total reactive power is

$$Q_{es} = Q_{se\_es} + Q_{sh\_es} \tag{19}$$

Under these circumstances, the peak power value for the entire apparent power from the equations [20, 21] is feasible.

$$\frac{\partial Q_{es}}{\partial \theta_{Vse\_es}} \tag{20}$$

$$\frac{\partial Q_{es}}{\partial |V_{se\_es}|} = 0 \tag{21}$$

The series converter maintains a steady regulated voltage across the vital load while connecting the output in series with the output of the non-critical load to handle voltage variations caused by the meteorological conditions of the hybrid model. The shunt converter compensates for the actual power demand of the shunt converter and maintains the DC link voltage. The voltage fluctuation on the input side can be balanced by a series converter and a non-critical load, and can therefore be called as Smart load.

Therefore, the purpose of controlling the series converter is to control the voltage on a non-critical demand while adjusting the voltage level. The clever coupling of an electrified spring demand and a non-critical demand can do this by altering the actual and reactive power usage. The control structure of series converters with hanging control is shown in Fig. 3 shown. Droop control has the advantage of coordinated control of reactive power compensation and voltage control between multiple electric springs without communication. Reference voltage and measured voltage can be deducted and delivered to PI controller to produce the needed real power P_(se_es) and Q_(se_es) is taken as 0. Using real power and reactive power and series converter current I_nc, reference injected voltage (V_(es_ref) and θ_(es_ref)) by series converter can be calculated as shown in Fig. 3. Reference voltage is modified using a droop gain to match the feeder voltage

3. HYBRID SYSTEM

Hybrid generation system with application of electric spring back-to-back converter for reactive power compensation and voltage regulation at load side is shown in Fig. 2. A rechargeable battery device, two generation modules (breeze and sun), and a common DC connection are used to supply power to the grid side through an inverter.

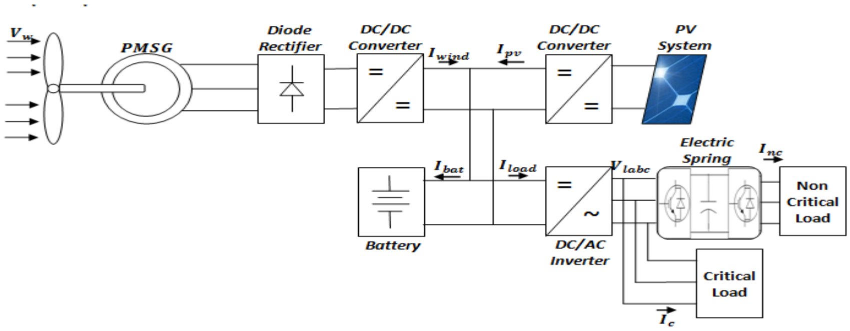

Fig. 2. Hybrid System

Case 1. Electric Spring Converter Hardware results

Hardware implementation of a Hybrid generation system with Electric spring back-to-back converter is designed and hardware results are compared with the simulation. A Hybrid generation system hardware is designed and the results are tabulated as below for variable wind and solar conditions.

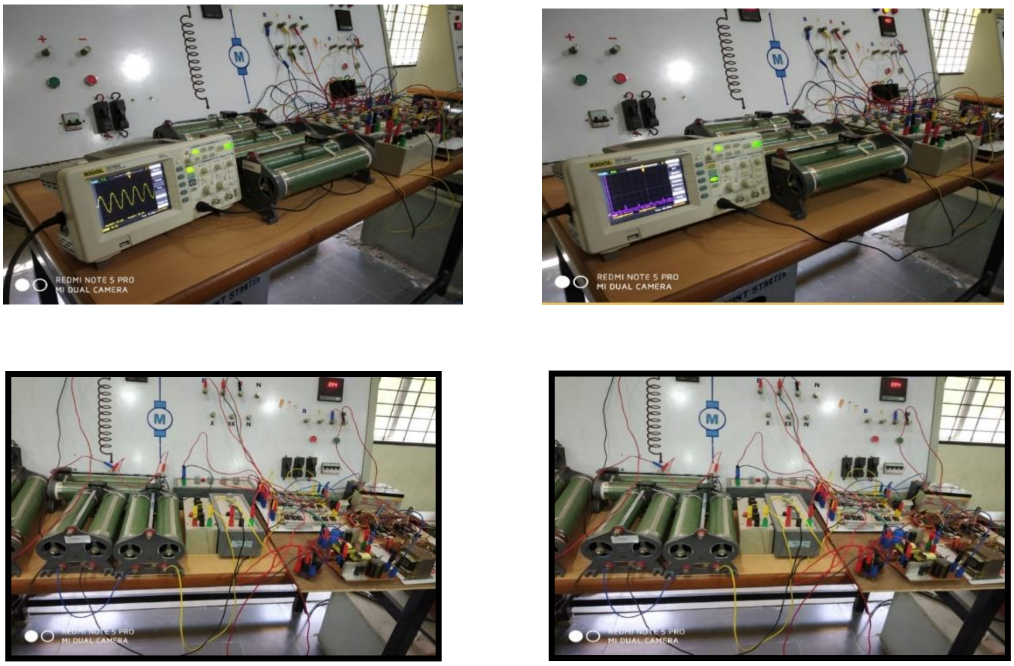

Fig. 3. Hardware Implementation of Wind and solar based Smart Grid

Case 2: Critical load of 170 W and 130 VAR and non-critical load of 170 W and 10 VAR are coupled to an electric spring

In this system, a back-to-back commutating electric spring is connected between the inverter and the critical load in line with the non-critical load. The AC voltage after changing the inverter after the LC filter is shown in the figure. 9. The load current after a series electric spring converter is shown in the figure. 10.

The RMS voltage of the load is shown in the figure. 11 and is nearly constant and is more variable, ranging from 0.98 to 1.02 with no electrified spring (0.5 to 1.2 pu). As seen in Fig., the load's active and reactive power.

Figure 13 displays the voltage at a steady load. The THD of the load voltage and current are shown in Figures 14 and 15. Table 1 is shown to compare simulation

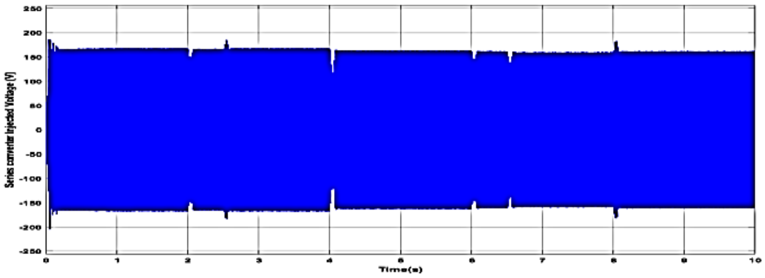

Figure 9. Inverter Filtered voltage

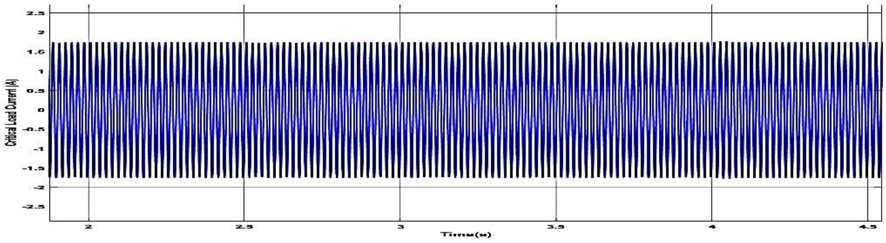

Fig 10. After the electric spring is connected, the load current

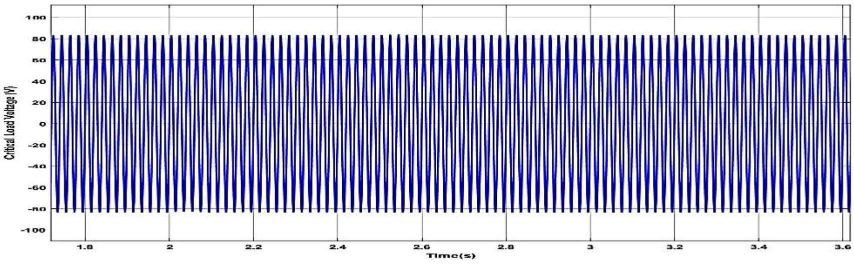

Fig11With an Electric Spring, RMS Load Voltage

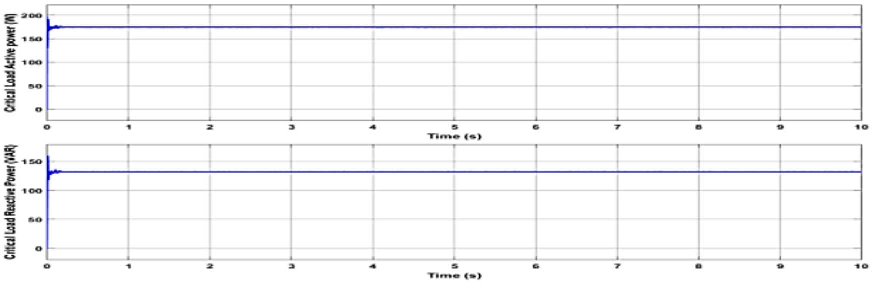

Fig 12. Reactive as well as Active Loading

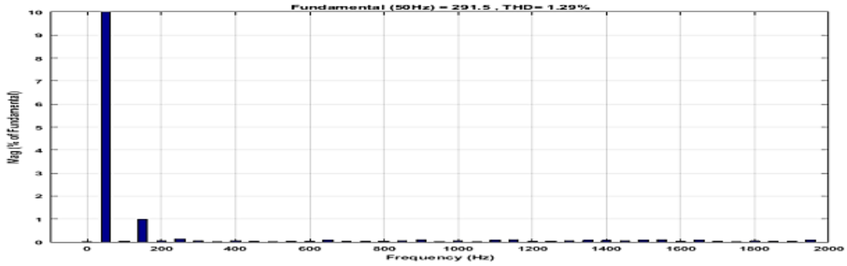

Fig13. Voltage Series Converter

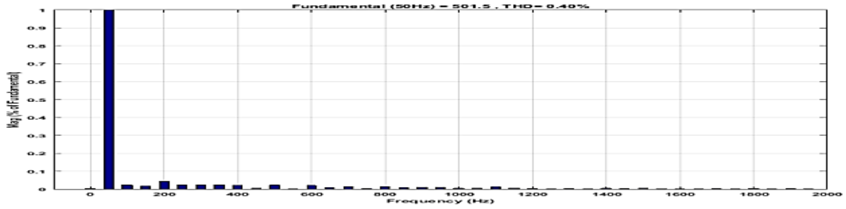

Fig 14: Charge current THD

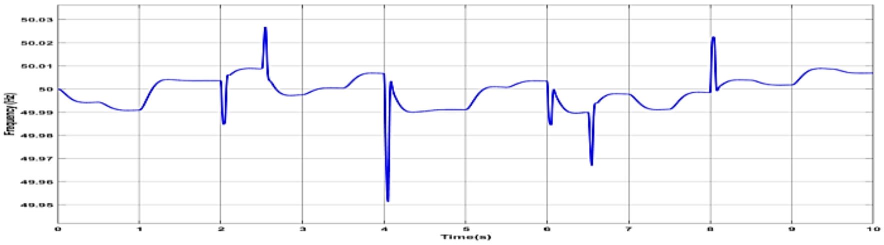

Fig 15. Voltage at Load Cycles

Table:1-Comparision of Hardware and simulation results

Parameter	**Hardware results of Electric Spring**	**Simulation Results of Electric Spring**
Voltage THD at Load	0.8	0.4
Current THD at Load	2.1	1.29
Power Factor	0.92	0.9826
% Voltage Variation	4.2%	2 %
%Frequency Variation	0.3%	0.1%

3. CONCLUSION

The back-to-back electric spring is connected to a hybrid system to improve voltage and frequency stability for critical loads and compensate for reactive power. The sun and wind are considered as energy sources and the line voltage is linked to the battery. The battery storage device is connected to withstand the maximum load. Since both renewable energy sources are sensitive to weather, the common DC bus voltage of the two energy sources is unstable. This affects the stability of critical and non-critical loads connected to the DC bus through the inverter. To improve voltage and frequency stability and to compensate for reactive power, an electric spring is connected to the converter between the inverter and the critical load. To achieve the electric spring effect, a control scheme is applied to both converters. Simulated findings with equipment and those from MATLAB/SIMULINK are used to validate the proposed converter in the hybrid model. The findings demonstrate that perhaps the electric spring back-to-back converter successfully balances reactive power while stabilizing frequencies and voltages.

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