Electric Spring for Voltage and Power Stability with Fuzzy Logic Controller

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Abstract: In this paper a single-phase electric spring is introduced at non-critical load for injection or absorption of voltage at the load. 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 noncritical 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 microgrids. The control schematic is updated with fuzzy interface system for better stability of electric spring voltage. A comparative analysis is carried out using MATLAB Simulink environment and results are shown in graphical representation.

Keywords: *Electric Spring (ES), Power Quality, Renewable Energy, Single-Phase Inverter, PI Controller, Fuzzy Logic Controller.*

I. INTRODUCTIOBN TO ELECTRIC SPRINGS

The growing incursion of renewable energy sources like biogas, wind power generation, tidal energy harvest and photo voltaic's normally impose new challenges to the potential power systems. Due to the sparsely distributed and intermittent characteristics of RESs, it is not simple to predict and control the total power generation straight away. Growing intermittent renewable energy sources may knock off balance of the ac mains voltage. Diverse schemes have been used lately to manage the distribution network voltage [1].

In a traditional power system, the generation side follows the load demand but in case of the renewable energy source-integrated power systems a new control mechanism is followed where the load demand follows the un-dispatch able power generation pattern by renewable energy sources. So as to achieve this control mechanism, various demand side management techniques are developed. These demand side management techniques are carried out in following four ways:

1. Daily task scheduling of variable power demands
2. Real time pricing
3. Use of energy storage systems for demand peak shavings
4. Remote control (ON/OFF) of smart loads

The load profiles that have predetermined behavior make use of the first and second methods of demand side management techniques. But they have a drawback of not being able to balance the generation and load at real time operations. The third method is best suited for real time power imbalances but it does not have satisfactory capacity and is not economical. Though the fourth method suits the real-time power balance but it is not apt for every consumer. In order to satisfy the instantaneous power balance, the last two methods are prompt solutions[2].

The electric spring (ES) is termed as a novel voltage compensator which is connected in series with a noncritical load so as to regulate the critical load voltage that is connected in parallel to the former. The voltage fluctuations are usually caused by load fluctuation, wind speed fluctuation, generator tripping etc. In bus bar (critical load) voltage drop condition, the electric spring shrinks the voltage of non-critical load in so as to support the bus bar (critical load) voltage. All the non-critical loads may not work satisfactorily under any voltage. The electric spring along with its control strategy is proposed for active and reactive power compensations and also for voltage control of critical loads on a given reference value along with the voltage control of non-critical loads amid a suitable boundary.

In other words, the Electric spring (ES) is proposed to bear the AC voltage of critical load and permit the voltage of non-critical loads to vary. The series connection of the electric spring and non-critical load are termed as smart loads. With either the injection or absorption of the reactive power, the electric spring control the voltage of critical load[4].

Usually, the electric spring is also implemented in the double voltage control i.e., to control both the load voltages in the distributed networks or microgrid in the grid connected mode. The active and reactive power compensation technique is used as control strategy so as to achieve this control scheme.

The electric spring along with non-critical load in a weakly regulated or stand-alone renewable energy source powered grid helps in providing voltage and power stability along with power factor corrections.

II. PROPOSED MODEL

The below figure 1 depicts the proposed circuitry of electric spring that is connected to a system. The electric spring in the below circuitry is realized through an inverter. This electric spring is usually driven by a current controlled voltage source; here it is connected to a renewable energy source powered microgrid. This electric spring is connected in series to non-critical load (for example refrigerator, air-conditioner), these two clubbed together is termed as smart load. This smart load is connected in parallel to the critical load (for example security system).

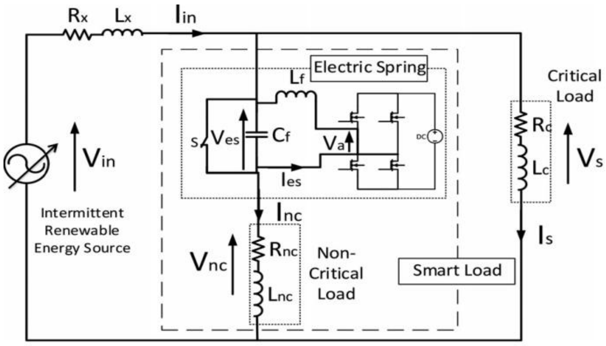

Fig.1 Outlay of electric spring connected in a circuit

A. PI Controller of the Proposed Electric Spring

The below figure 2 depicts the PI controller components that is used for the control of the electric spring.

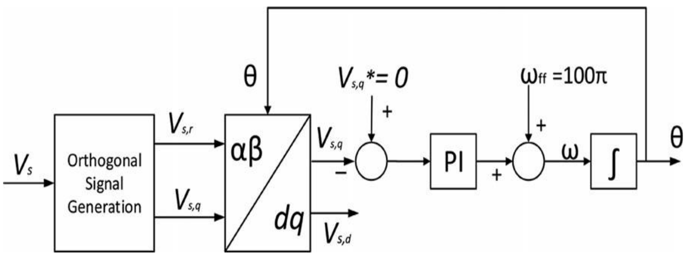

Fig.2 PI Controller

The electric spring with PI control scheme helps in injecting both real and reactive power in the system thereby improving the voltage support and power factor of the system. It also helps in maintaining the value of line voltage to a reference voltage and increases the active power consumption by the noncritical loads. It also accelerates the output response and also helps to remove the steady state error.

B. Control Scheme through Fuzzy Controller

Fuzzy controller is one of the most widely used controllers in the present scenario like air conditioning, security systems, anti-braking systems etc. Generally, a control system is an arrangement of certain components that is designed to alter another physical system so that it may exhibit definite desired characteristics.

Importance of using fuzzy logic in control systems

- In traditional control schemes we need to know about model and objective functions, which is difficult in most of the cases. This is not required in fuzzy logic
- human expertise can be utilized for designing controller
- fuzzy control rules such as IF-THEN can be effectively used for designing

Fuzzy Logic Control (FLC) Design Assumptions:

The basic assumptions made while designing fuzzy control system are as follows:

- Input, output and state variables are accessible for observation and control.
- There exists a knowledge body that has linguistic rules and a set of input-output data set from where rules can be extracted.
- A solution exists
- Acceptable range of precision must be there in designing of FLC
- The stability and optimality issues must be open in designing of FLC

C. Control Architecture of FLC

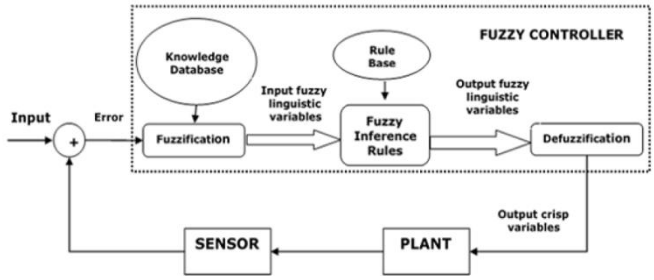

Fig. 3 Fuzzy logic control architecture

The main components of above stated FLC architecture are as follows:

1. **FUZZIFIER:** converts the crisp input values into fuzzy values
2. **FUZZY KNOWLEDGE BASE:** stores the information about all the input-output fuzzy relationships
3. **MEMBERSHIP FUNCTION:** Let X_{is} be a set of objects which is called the universe, whose elements are denoted by x. Membership in a subset A of X is the membership function, mA from X to the real interval (0, 1). The universe is all the possible elements to be taken in the particular context. A is called a fuzzy set and mA is subset of X that doesn't have sharp boundary. mA is the grade of membership x in A. The closer the values of mA to 1, the more x belongs to A. The domain is the total allowable universe of values of the fuzzy set. The domain is a set of real numbers, increasing steadily from left to right where the values may be both positive and negative. This can be shown as

$$A = \{(X, \mu_A(x)), x \in X\} \qquad (3.1)$$

Support of a fuzzy set A in the universal set X is the crisp set that contains all the elements of X that has a non-zero membership grade in A. That is depicted as

$$\text{SuppA} = \{x \in X | \mu_A(x) > 0\} (3.2)$$

With a finite support, let x_i be the element of the support of fuzzy set A and that m. μ_a grade of membership in A. Then A is given by convention as,

$$A = \frac{\mu_1}{x_1} + \cdots + \frac{\mu_n}{x_n} \qquad (3.3)$$

Where X is an interval of real numbers and a fuzzy set A is expressed as

$$A = \int_x^n \mu_A(x)/_x \qquad (3.4)$$

4. **FUZZY RULE BASE:** stores the information about the operation of the process of domain.
5. **INFERENCE ENGINE DECISIONS:** is the kernel of FLC that replicates human decisions by executing approximate reasoning.
6. **DEFUZZIFIER:** converts the fuzzy values into crisp values obtained from fuzzy inference engine

D. Advantages of Fuzzy Control

The advantages of fuzzy control over other adaptive control can be summed as follows:

- It shares output to input, without much perceptive of all the variables, allowing the design of system to be more precise
- The linguistic, not numerical; variables make the process similar to that of human thinking process
- They are more robust as compared to PI controllers because of their ability to envelop a enormous collection of operating conditions.
- FLC is economical
- FLC is customizable
- FLC is reliable
- FLC has higher efficiency
- Provides better stability

IV. RESULT ANALYSIS AND DISCUSSION

The proposed algorithm of electric spring is implemented with the help of MATLAB (R2016). The signal processing toolbox of the MATLAB library consists of various functions that aids in methods like shifting, scaling etc.

A. Simulation Parameter

Name of parameter	Unit and Value
Vrms (Line Voltage)	238V (Over Voltage)
Frequency	50Hz
Line Impedance	Rx =0.1 Ω & Lx = 2.5 mH
Non-Critical Load	6.11+ j0.44Ω
Critical Load	11+j11Ω
Switching Frequency	20 KHz
Proportional integral -1	Kp = 3, Ki = 10
Proportional integral -2	Kp = 3, Ki = 10
Out Put of Low Pass Filter	Inductance (Lf =1.92 mH,Cf = 13.2 µF)

B. Simulation Results and its Discussion

Description 1 (Fig. 4): The below figure showcases the proposed circuit topology of electric spring (has similar construction as that of an inverter) that is connected to non-critical load. The electric spring is driven by a current controlled voltage source. The electric spring is connected in series to the non-critical load and jointly it is stated as smart load. This smart load is connected in parallel to critical load of the system.

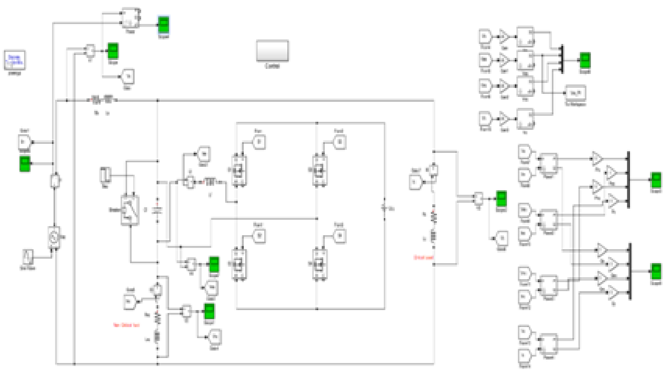

Fig.4 Proposed circuit topology with electric spring connected to non-critical load

Description 2 (Fig. 5): The below figure showcases the control scheme of the proposed electric spring topology. Here the control scheme used is the PI control. This is an improvised version of conventional control method of electric spring. This not only improves the power factor, voltage support and active power consumption of non-critical loads but also increases the stability of the system.

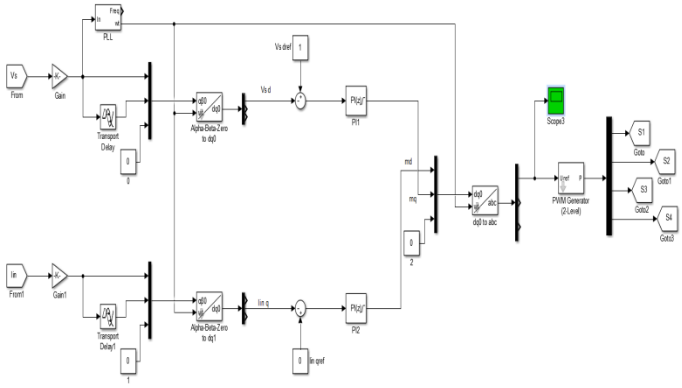

Fig.5: Control scheme modeling with PI controller

This is an updated version of PI control method of electric spring. This improves the power factor, voltage support and active power consumption of non-critical loads.

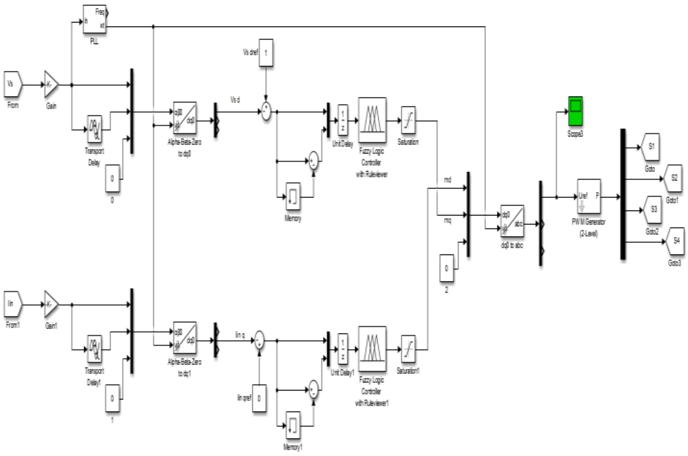

Fig. 6 Control scheme update with fuzzy interface system

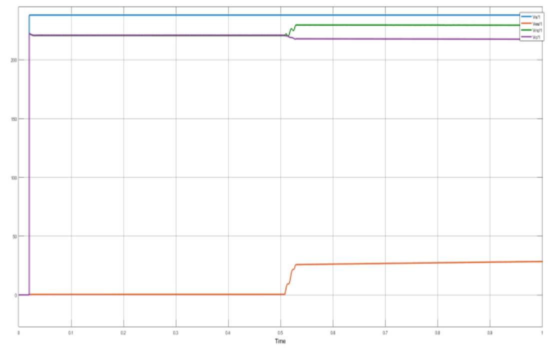

Fig.7 Voltage magnitudes of all devices with electric spring connected at 0.5sec in over voltage condition

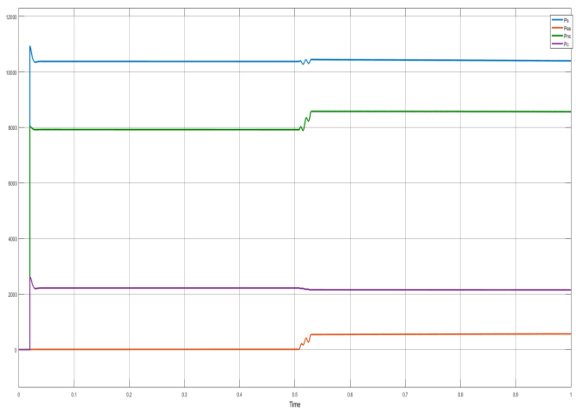

Fig.8 Active power of all devices with electric spring connected at 0.5sec in over voltage condition

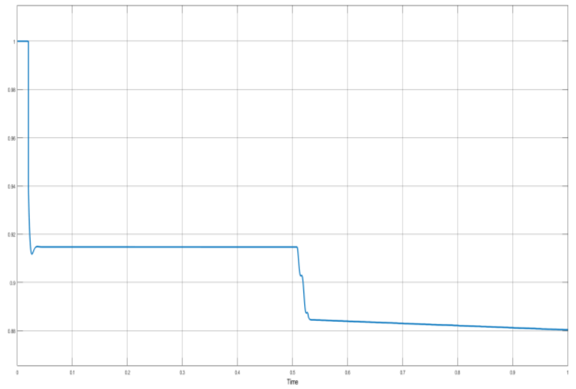

Fig.9 Power factor of source with electric spring connected at 0.5sec during over voltage condition

The below figure 10 shows the comparison of active power when the electric spring is controlled by PI controller and Fuzzy controlller respectively. It can be seen from this figure that the fuzzy controller provides better stability to the system when compared to the PI contoller.

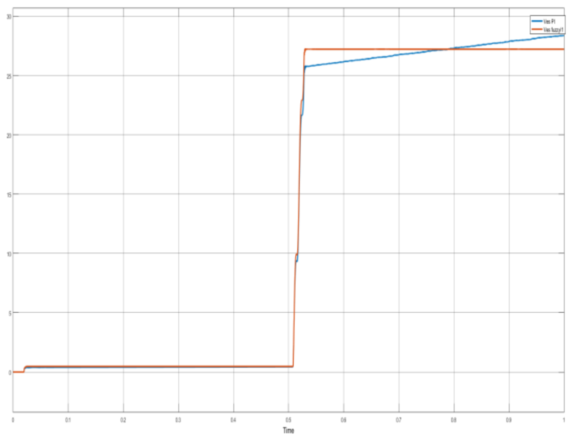

Fig.10 Electric spring active power comparison with PI and fuzzy controllers

CONCLUSION

It can be concluded from the obtained results that, when an electric spring is connected to the non-critical loads, there occurs some changes in the voltage magnitudes. The injected voltage by the electric spring is well synchronized with the source voltage. The electric spring is an inventive solution for voltage and power stability issues associated with renewable energy source driven power grids. The frequent updates in the electric spring and its control schemes paved way for maintaining the line voltage to a reference voltage of 230V, constant power to critical loads and overall power factor improvement of the system. The use of fuzzy control aids in the improvement of the stability of the injected voltage thereby increasing the overall voltage stability of the devices connected to the system.

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