SURVEY AND IMPLEMENTATION OF VOLTAGE AND FREQUENCY FLUCTUATION MITIGATION USING ELECTRIC SPRING IN IEEE-9 BUS SYSTEM

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ABSTRACT

Electric spring is a recent growing concept in power system and control engineering. Electric spring is able to handle fluctuations at demand side because of dynamic changes in load. Similar to facts devices it injects reactive power when fault occurs in transmission line, as well it have ability to make a power stable at demand side if demand changes. This paper shows that Electric spring is able to cope with fluctuations in load as well generator tripping. This paper shows Electric spring simulation implementation with IEEE 9 bus system and one of the wind farm as additional source and varying load condition. Electric spring mitigates fluctuation in voltage and frequency and helps to provide stable system response. Sinusoidal pulse width modulation technique is used to generate pulses to trigger inverter to convert DC signal from battery storage unit to AC supply.

Key Words: *Electric spring, IEEE - 9 bus, frequency mitigation.*

I. Introduction

Current times, as Electric spring is a growing in demand and concept, it needs to do more research and to discover effective control methodologies for it. This control methods helps to improve voltage stability and transient's rejection.

In 2015, E.F.Areed proposed an Electric spring approach and shows reduced dependency on communication technology. He proposed a concept for demand side management using ES to regulate main voltage and allowing smart load to follow power profile. He used PI controller and designed PI parameters from genetic algorithm to minimize error. He also investigated sudden change and disturbance operating conditions are investigated. [1] ES is used for demand side management through modulation of non-critical load in response to fluctuations in renewable energy sources. [2] When there is a nonlinear or unbalance load, at that time power quality, voltage sag and swell may occurs. Statcom and electric spring can overcome this issues. [3] When multiple electric springs are used in Microgrid, then distributed control strategy is used and they proposed a cooperative control. By ensuring the reactive power utilization ratio of each ES to converge to given set point, the trade-off between reactive power sharing capacity and voltage requirement from demand side can be compensated. [4] Voltage and frequency fluctuations in Microgrid can be mitigated by using ES. ES can mitigate voltage and frequency fluctuations mitigation caused by variation in wind for wind farm, intensity in PV or because of generator tripping. Phase and amplitude can be controlled to adjust active and reactive power. [5] When there is a fluctuations in power generated by wind turbine, electric spring can regulate the supply to mains voltage and electric spring found much effective for this much operation and it is a recent advancement. It is a new form of power system stability solution that is independent of information and communication topology. [6] As the smart load is connected in system it has a characteristics of following power generation by changing its load demand dynamically and regulating the voltage at a point in distribution system where it is connected. It is projected to mitigate voltage and frequency fluctuations when numbers of small renewable energy sources are connected. [7] Paper presents a method to mitigate neutral current in three phase systems using concept of ES. The ES consists of a fast acting passive devices controlled through power electronic switches, connected to building Microgrid based on classification of critical and non-critical loads. His proposed method results in better equipment safety and long life of critical building load. [8] ES is Emerging technology proven to be effective in stabilizing smart grid with variation in power generation of renewable energy sources and enabling load demand to follow power generation. Like other facts devices it also provides reactive power compensation and automatic power variation in noncritical loads. [9] C.K.Lee proposed that Electric spring can be operated in number of following ways. [10]

1. Inductive power (+jQes) compensation,

2. Capacitive power (−jQes) compensation,

3. Positive real power (+Pes) compensation,

4. Negative real power (−Pes) compensation,

5. Inductive plus positive real power (+jQes + Pes) compensation,

6. Inductive plus negative real power (+jQes − Pes) compensation,

7. Capacitive plus positive real power (−jQes + Pes) compensation;

8. Capacitive plus negative real power (−jQes − Pes) compensation.

II. Theory

Power system stability is classified as: Rotor angle stability, Frequency stability and Voltage stability. Possibility of advanced controls are, Generator excitation control, Dynamic braking, Generator tripping, Fast phase angle control, Series and shunt active power filters, Statcom, UPFC, SMES, HVDC link supplementary control etc.

Critical load requires fixed voltage and power for its operation, like devices in house, buildings etc. whereas non critical load is which can bear some fluctuations in its supply like Air conditioner, Electric heaters etc. Electric spring is a device which can be connected in series with non-critical load and it can bear a voltage fluctuations like which may occur in renewable energy sources because of variations in their inputs. Series connection is utilized in maintaining constant voltage Vs across device.

Operating Principle

(a) Capacitive mode (b) Inductive mode

Figure 1 Phase diagram of Electric spring with Resistive-Inductive Load [11]

Consider a phasor diagram as shown above. Vs is source voltage and Vo is load voltage. Va is compensating voltage from Electric spring and Io is load current. Electric spring can be utilized for both active and reactive power compensation. For an ES to be loss less, Voltage from ES should be perpendicular to Io load current. This means for resistive inductive load, Va is leading Io by 90degree and gives capacitive compensation and vice versa for inductive compensation. Total sum of load voltage Vo and ES voltage Va is equal to device voltage Vs. In steady state condition

$Ps = P0 \pm Pa$

$Qs = Q0 \pm Qa$ …… (1)

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

$$P_a = |V_a| \times |I_0| \cos(\delta + \phi_v)$$
$$Q_a = |V_a| \times |I_0| \sin(\delta + \phi_v) \quad \ldots\ldots (2)$$

$$P_0 = |V_0| \times |I_0| \cos\theta$$
$$Q_0 = |V_0| \times |I_0| \sin\theta \quad \ldots\ldots (3)$$

$$P_s = |V_s| \times |I_0| \cos\delta$$
$$Q_s = |V_s| \times |I_0| \sin\delta \quad \ldots\ldots (4)$$

Where ϕ_v is the phase angle between the ES and power supply voltage, δ and θ are the power factor angle of the power supply and load, respectively. From (1)–(4), the load power can be calculated as shown in

$$P_0 = |V_s| \times |I_0| \cos\delta - |V_a| \times |I_0| \cos(\delta + \phi_v)$$
$$Q_0 = |V_s| \times |I_0| \sin\delta - |V_a| \times |I_0| \sin(\delta + \phi_v).$$

III. PWM Control Method

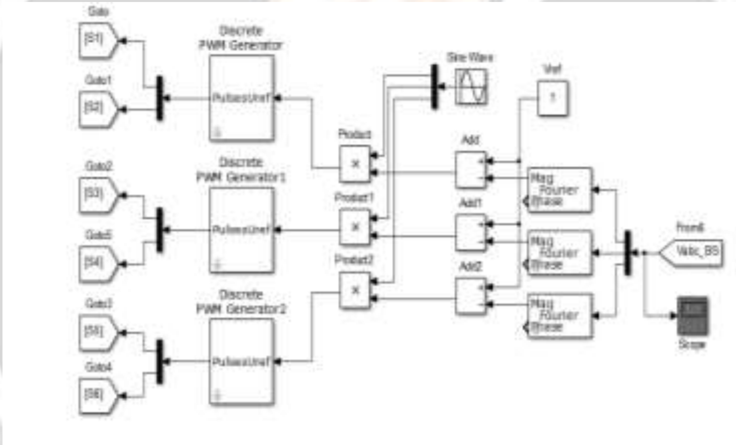
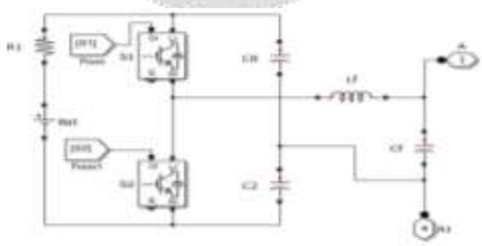


Figure 2 PWM Control circuit for Electric spring

PWM is a gate signal generation method. It compares actual load voltages with reference voltage and generates difference, this difference is given to sinusoidal signal with frequency f 50Hz at a phase of 0, 120 and -120 Degree, and generated signal is given to discrete pulse generator which generates pulses accordingly.



LC filter for Harmonic reduction in SPRING

Figure 3 Electric Spring with LC filter

LC filter reduces harmonics in generated AC supply. Here we are converting fixed DC sources to AC and this voltage waveform generation is controlled by gate signals which are discrete. So, if we didn't connect LC filter, voltage generation will be discrete, and as we require pure AC, LC filter reduces harmonics, and appropriate design of filter parameters gives pure AC sinusoidal waveforms.

ES Parameters:
Filter inductance: 0.4 mH
Filter capacitance: 13µF
DC link: CS = 4000 µF, Vdc = 40 kV, and Vac = 35 kV
PWM switching frequency: 1 kHz

9 Bus system data: Line Parameters

Line	Resistance	Susceptance
1-4	0.00000	0.0000
4-5	0.0170	0.1580
5-6	0.0390	0.3580
3-6	0.0000	0.0000
6-7	0.0119	0.2090
7-8	0.0085	0.1490
8-2	0.0000	0.0000
8-9	0.0320	0.3060
9-4	0.01000	0.1760

Table 1 IEEE 9 Bus data

Generator Data

Data	Generator 1	Generator 2	Generator 3
Phase to Phase rms Voltage (V)	16500	18000	13800
X/R Ratio	7	7	7
3-Phase Short circuit level at base voltage (VA)	128M	192M	128M
Base voltage Vrms ph-ph	5000	5000	5000

Table 2 Generator data

IV. MATLAB Implementation

Case 1: Fix Load

Here IEEE 9 bus system is implemented to prove the concept of Electric spring, and non-critical load is connected directly to bus 6 through circuit breaker as well through Electric spring.

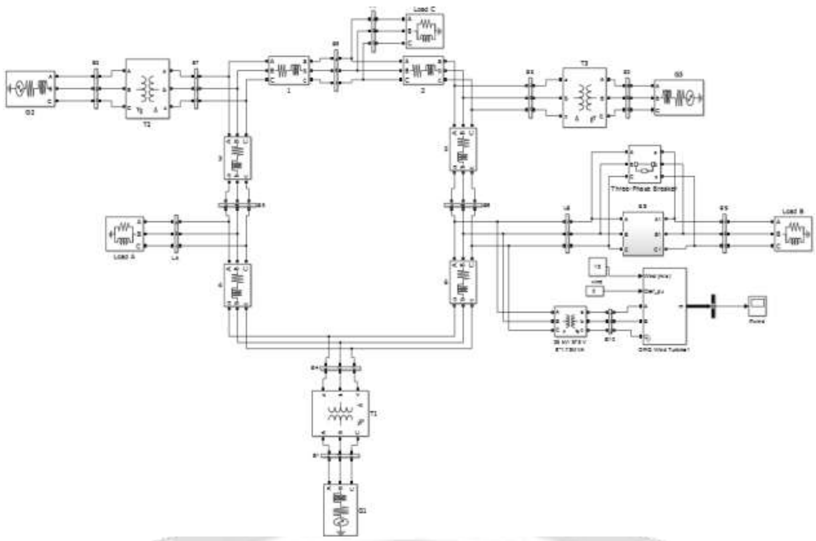


Figure 4 Case 1: Fix Load, Fix wind speed MATLAB Implementation

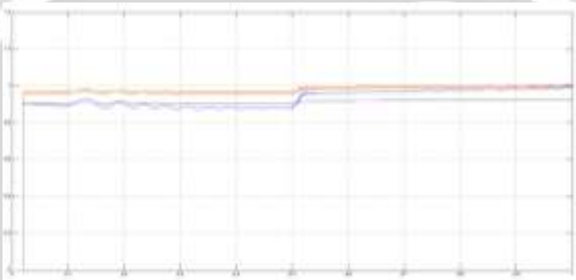


Figure 5 Case 1: Voltages on Each 9 buses

This is a power measurement across all nine bus. Here in waveform it can be seen that at 0.5 time voltage stabilizes to 1p.u. Circuit breaker was close up to time 0.5 and load was directly connected to bus 6, and when circuit breaker opens at 0.5 time, then spring comes into existence and load is connected through spring, so, spring provides enough boosting to load, and power is maintained to 1p.u.

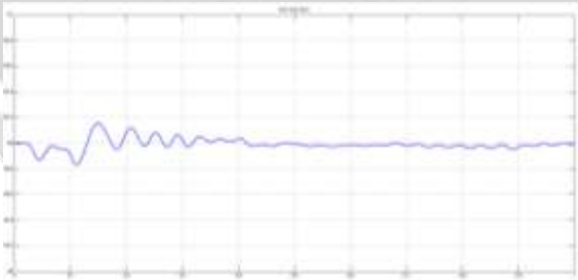
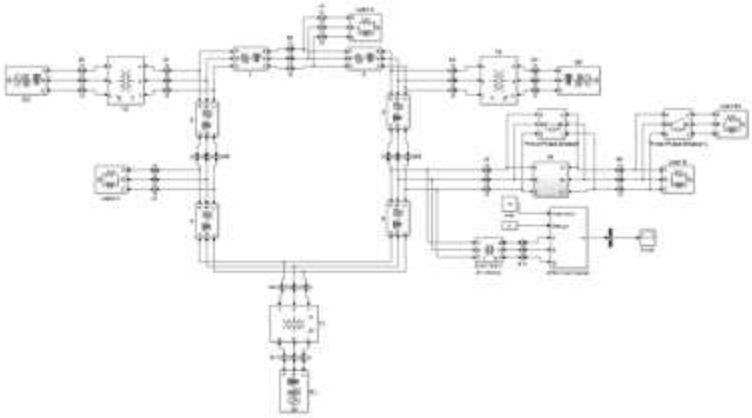


Figure 6 Case 1: Frequency on bus 6

From this frequency waveform it can be concluded that when spring was not connected till 0.5 time, there was variation in frequency because non critical load was connected directly to bus 6, and when spring comes into existence for non-critical load, frequency is stabilizes to 50Hz, so we can say voltage and frequency fluctuations can be mitigated through Electric spring.

Case 2: Variable Load

This case is similar to case 1, only the difference is additional load is connected through circuit breaker at time



0.6

Figure 7 Case 2: Variable Load, Fix wind speed MATLAB Implementation

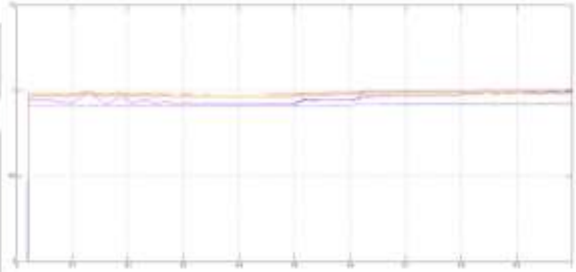


Figure 8 Case 2: Voltages on Each 9 buses

From this waveforms it can be concluded that till time of 0.5 load is directly connected to bus 6, and after 0.5 time load is connected through spring and power level is improved near to 1 p.u, and when at time 0.6 additional load is connected through circuit breaker, and still spring maintains voltage level to 1p.u as required.

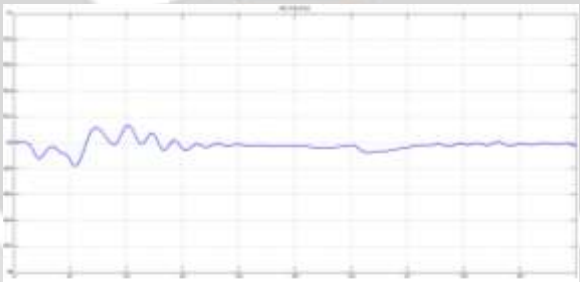


Figure 9 Case 2: Frequency on bus 6

From this frequency waveforms, it can be concluded that when load was directly connected to bus 6 without spring, at that time because of non-critical load, there was a fluctuations in frequency, and when spring comes across load, frequency improved to stable 50Hz, and when additional load added, then still frequency is maintained at 50Hz.

Case 3: Generator Tripping

In this case load is connected to bus 6 thorough circuit breaker. At 0.5 circuit breaker opens, and load connects through Electric spring. This case is different from previous two. In this case generator trips at 0.7time.

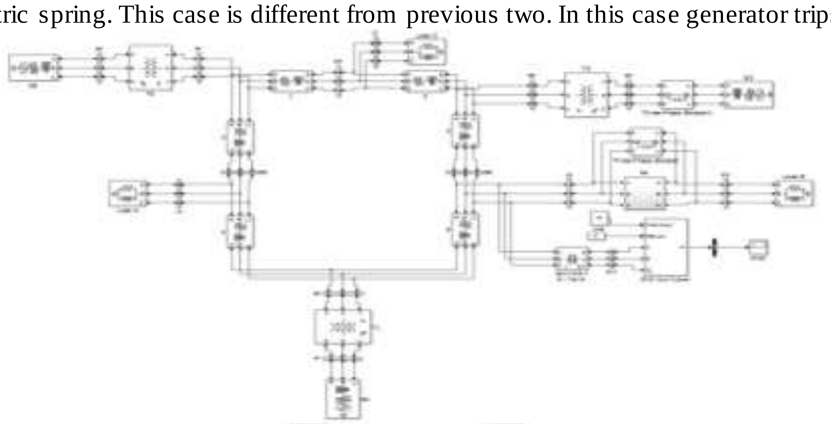


Figure 10 Case 3: Fix Load, Fix wind speed, Generator trip MATLAB Implementation

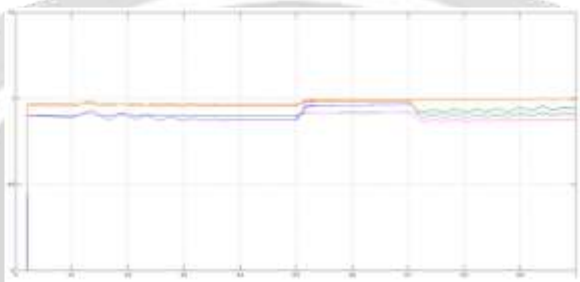


Figure 11 Case 3: Voltages on Each 9 buses

From this waveforms it can be concluded that upto 0.5 time as load is directly connected to bus 6, voltage is approximately at 0.87 to 0.9 p.u, and after 0.5 time, Electric spring comes into existence and load is connected through it, and power is improved to 0.95 to 1p.u. At 0.7 time, generator trips but still spring tries to maintain power level, and it is maintained nearly at 8.87 to 9.97 p.u. [12]

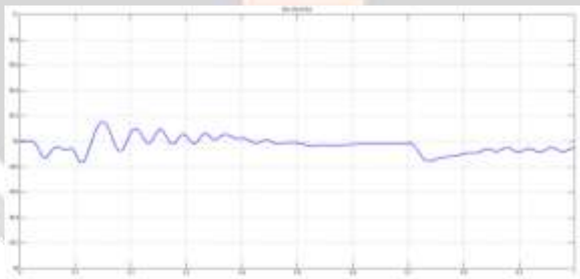


Figure 12 Case 3: Frequency on bus 6

From this frequency waveforms it can be concluded that even generator trips, frequency is maintained nearly to 50Hz because of Electric spring.

V. Conclusion

From the above simulation based experiments we can conclude that Electric spring is an effective power electronic device for mitigating voltage and frequency fluctuations caused by dynamic changes in load as well because of generator tripping. Electric spring works well with SPWM control method to trigger inverter to inject power and it helps to stabilize frequency at fix level.

VI. References

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