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Comparison of Voltage Regulation of a Smart Load for 3 Bus System and 15 Bus System under High Penetrationof Wind Energy System

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Abstract: Modern study about utilizing energy from renewable energy sources was stimulus due to emerging oil crisis in older days due to uncontrolled use of conventional energy sources. Renewable Power Generation from wind and solar energy has become a significant proportion for the overall power generation in the grid. High penetration of Renewable Power Generation (RPG's) effect reliable operation of bulk power system due to fluctuation of frequency and voltage of the network. The main objectives of high penetration of Renewable Power Generations in distribution system are Regulation of voltage, Mitigating voltage fluctuations due to flickers and Frequency control. The design and control of voltage regulation system using smart loads (SL's) under large penetration of renewable energy system in distribution level is to be studied with the help of FACT devices like Static Compensator (STATCOM) and It is one of the fast active devices with accurate voltage regulation capability and most importantly for the sensitive/critical loads. Electric spring (ES) is proposed as compelling technique for guideline of framework voltage under fluctuating RPG's with next to no guide of correspondence framework [1]. It is a converter-based framework with self-commutated switches in span design, which is associated with non-basic burdens in series to go about as savvy load. These Smart Loads are controlled to direct voltage across basic burdens and hence partaking popular side administration. Expanded entrance of RPG's, basically factor speed wind energy transformation framework is having impact on voltage and power quality [1][2]. In this paper, A contextual analysis of impact of variable speed wind energy framework on voltage is completed and which is demonstrated with fluctuating breeze speed. Execution examination of keen burdens are to be contrasted and existing receptive power compensator burdens and Improvement in voltage profile on test feeder is directed on a 3 Bus system and 15 Bus system.
Keywords: Renewable energy system (RES), Electric spring (ES), STATCOM, Voltage Flicker, Smart load.

I. INTRODUCTION

Electricity now plays a vital role in day-to-day life, according to recent trends. Petroleum products (coal, flammable gas, and petrol), Thermal power, and Sustainable power sources are the three major energy classifications for the electricity age. The majority of electricity is generated by steam turbines that use petroleum products, as well as atomic, biomass, geothermal, and solar-oriented nuclear power. The current focus on using energy from environmentally friendly power sources has improved as a result of the escalating oil crisis caused by the unrestrained usage of conventional energy sources. Environmental changes and the increase in CO2 levels have become a big issue influencing the global climate as a result of these petroleum products and thermal electricity. Along these lines, environmentally friendly power sources have become an important part of the electricity generation process. In the lattice, Inexhaustible power age from wind and sunlight-based plants is expanded and transformed into a critical extent of the general power age (grid system). Fig 1.1 depicts the overall matrix mix of interconnected framework. According to 2014 electricity age reports, biomass, wind, and sunlight-based power plants provided 60% of electricity age in Denmark; non-hydropower sustainable supplies accounted for 30% of burden interest in Portugal and Spain had 29% environmentally friendly power age. The progress of sustainable power is exciting, but it faces several challenges in the power business. In terms of diverse energy assets, the highest commitment in terms of power generation is through the use of wind energy. The electrical exhibition of wind energy making framework is depicted by the power quality related to a breeze (wind) turbine [7]. It reflects the impact of a breeze turbine on the power and voltage nature of the framework, as well as the age of lattice impedance [2]. For wind turbines, the issue of power quality is critical. in recent years, there has been a broad and rapidimprovement in the usage of wind energy. The individual units can have a huge capacity of up to 5MW, taking care of circulation organization [7], especially with clients who are close by. Using rapidly varying voltage fluctuations due to the concept of wind, it is difficult to further increase the power quality with a simple compensator.

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To replace the traditional reactive compensator, advanced responsive power compensators with quick control and power electronic devices have emerged. A crucial prerequisite for maintaining power matrix reliability is a balance between the power generated and the heap request (load demand). There are several control strategies incorporated in existing power frameworks to meet the solidity of the power framework in order for the power age to follow the heap interest. Because of the significant variance, true power quality difficulties arise as the admission level of inexhaustible sources rises over time. Different issues arise from the insufficient changing parts of environmentally friendly power sources, such as the difficulty in predicting the framework's power stream, and it will not be difficult to undertake power stream examination midway in the keen lattice frameworks[6]. Further improved load management solutions are required to respond to these expanding features and eccentric nature of environmentally friendly power sources.

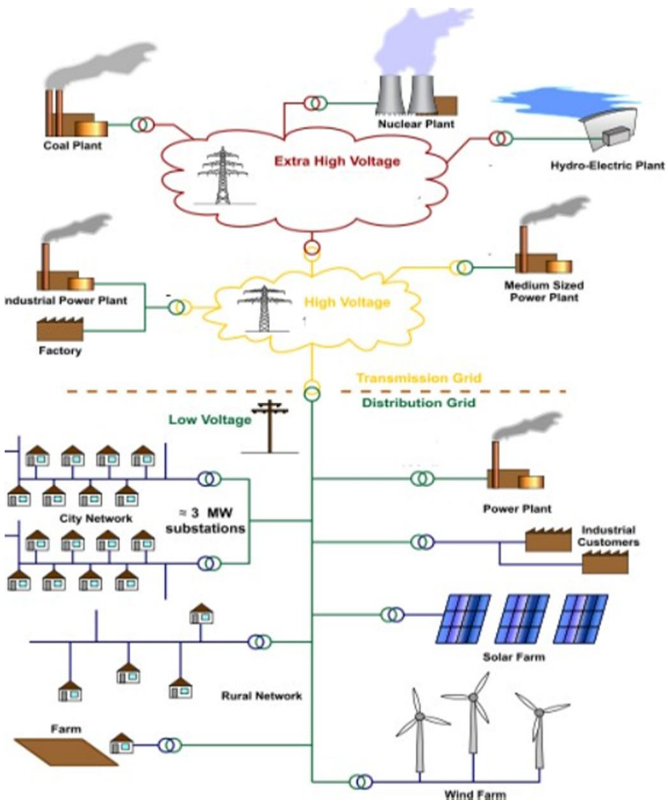

Fig 1. Grid integration of interconnected system

Regulation of voltage, moderating voltage change due to flashes, and recurrence(frequency) control are the essential aims for high infiltration of Sustainable Power Ages. Various established solutions are available to address the issues with high RPG entry. Various strategies are used to achieve the heap age balance among them. They include the use of energy storage components, a constant evaluation strategy, scheduled load shedding, and direct ON-OFF management of specific loads, among others. Although the conventional technique for Booked burden shedding is a common strategy for load power regulation, it is not useful for dynamic power balance on a continuous basis. Ongoing power homeostasis can be achieved by controlling the working season of high-power loads, such as refrigerators and cooling systems, and by using a turn-on/off method. However, the constant turning on and off of electrical devices has an effect on consumer burden and resistance. Energy hoarding components are now widely regarded as the most effective means of achieving power balance. With the predicted size of battery storage components, pricing is also quite high, and removal of these batteries owing to environmental concerns is limited due to their size. Furthermore, for voltage regulation in medium voltage and low voltage dispersion networks, tap-changing transformers or potentially exchanged capacitors/reactors are used, and FACT devices such as STATic Compensator (STATCOM) are used because it is one of the most effective devices with precise voltage regulation ability, especially for the delicate/basic loads. According to research published in [4] the capacity required of energy storage devices may be decreased by up to 50% when ES is used. The extended operating modes and control implementation of ES to build smart loads are explained in article [15].

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II. METHODOLOGY

Smart loads -based technology is an unique demand-side management solution for following the power generation-load curve when power generation is irregular [9], [13]. In a classical sense, these SLs are a sort of reactive power compensator with input voltage control rather than output voltage control. It can be deployed in a variety of locations depending on the voltage support requirements. Voltage flickering is a phenomena that occurs when the load on the grid changes, which is most commonly associated with the penetration of RPG's into the grid. Low frequency voltage fluctuation, which occurs in the range of 0.05-40 Hz and irritates human eyes, is known as this. There are numerous ways for reducing flicker sensitivity, however they all have their limitations due to the resistive structure of the distribution network. Thus, the usefulness of SLs in reducing voltage flickers is investigated in order to improve voltage quality at load terminals.

Table 1. Smart loads used for voltage regulation

Application	Appliances
Heating	Microwave Ovens ,Space and Water Heaters
Cooling	Blowers Refrigerator, Heat pumps
Lighting	Passive LED lights ,Incandescent lamps
Mechanical ventilators	water pumps ,Fan, blowers
Others	Dish washer, washing machines

The smart load, which is connected in parallel to the critical load to provide voltage support, is made up of ES and non-critical loads coupled in series. Loads are divided into critical and non-critical categories based on their sensitivity to voltage changes. Critical loads require regulated voltage across to maintain constant load power consumption, but non-critical loads can endure voltage variations and can even change their power consumption when the voltage changes. Smart loads operate based on NCL characteristics and ES control operations, so that voltage across ES controls active and reactive power consumption of SLs in response to variations in renewable power output. Smart loads consume more real and reactive power to compensate for the rise in voltage during each cycle of high renewable power generation. Similarly, with less power generated at the renewable source bus, voltage management was achieved by delivering reactive power and SLs were used to reduce real power usage.

III. TEST SYSTEM

Fig 2 shows the SLs layout used in each step in a schematic illustration. Smart load is defined as an electric spring in combination with a dissipative noncritical load in the distribution system. The modulation index and angle govern the amplitude and angle of the electric spring's voltage. The distribution system consists of a power grid that provides electrical energy, as well as an internal impedance matching system and a renewable energy producing system.

The distribution network transports energy to linked loads, which are divided into critical and noncritical loads. To maintain the main grid voltage, the voltage across the electric spring changes in response to RPG uncertainty, resulting in load consumption to track the power generation. A controlled current source is used to imitate a renewable energy source, causingthe main voltage of the load bus to fluctuate about its nominal value. NCL considers Znc to be its load impedance. With NCL, an ES is connected in series. The ES with dc bus injects a regulated magnitude of voltage in quadrature of load current to achieve a lossless converter system.

To examine the effect of wind energy system intermittency on voltage at load bus, a simple case study on a three-bus system is presented first, in which a MW range PMSG wind energy system is combined with grid and distribution loads of both critical and NCL load characteristics. Because wind speed variations are considered stochastic and periodic, the output power of WECS is observed to vary. According to the results of the analysis, a comparable ES design is recommended to regulate the voltage at the load bus.

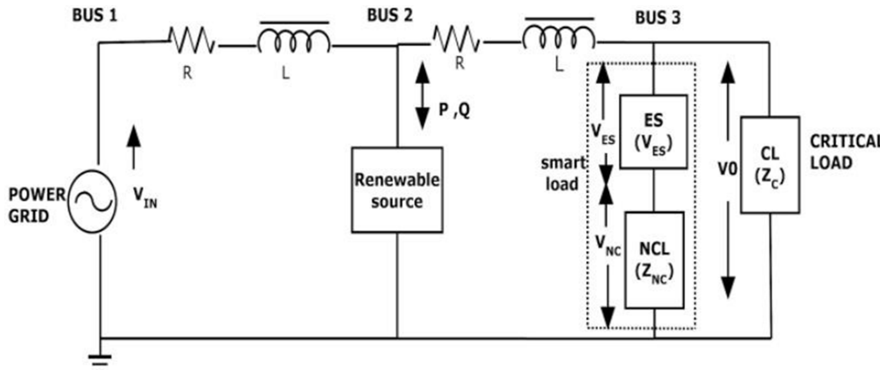

Fig 2. Structure of STATCOM based controller

A case study on the performance of individual ES with STATCOM is presented to explain the reactive power requirements of both ES and STATCOM in order to achieve the same voltage regulation. The case includes modelling of a single phase distribution network as shown in Fig 2 with a smart load arrangement that mimics the intermittent nature of RPGs. With injection of changeable real and reactive power, the controllable current source provides voltage variation across the load bus.

Simulations under various types of load, such as R type, RL type, and RC type, are used to investigate the performance of ES. STATCOM [12] is modelled using a controlled voltage source in series with impedance.

IV. SYSTEM CONFIGURATION AND PRINCIPLE OF ES

Fig 3[11] shows a converter-based system using a single phase H bridge inverter. The circuit uses a complete bridge inverter with a capacitor on the dc side and an LC filter on the ac side. The MOSFET gates are driven by the control signal from the PWM generator. The voltage across capacitor C on the ac side, i.e. the electric spring voltage, will be controlled by this. To generate the control signal, input voltage comparison controllers are used.

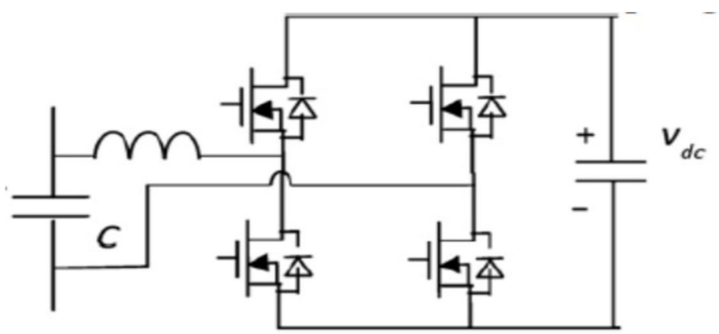

Fig 3 Circuit diagram of ES arrangement for each phase

The principle of action of ES is similar to that of a mechanical spring, and is based on Hooke's law, which states that the forceof an ideal mechanical spring is proportional to the displacement of the spring. As a result, an electric spring can support electricvoltage, store electric energy, and dampen electric oscillations.

$$q = \begin{cases} C\,v_a & \text{inductive mode} \\ -C\,v_a & \text{capacitive mode} \end{cases} \qquad (1)$$

$$q = \int i_c \, dt \qquad (2)$$

$$PE = \frac{1}{2} C\, v_a^{2} \qquad (3)$$

Where electric charge (q) stored in a capacitor with capacitance C, V_A represents corresponding voltage across the capacitor, and i_C denotes current through capacitor. Equation (1) depicts the functions of the electric spring in terms of controlling the charge stored in the capacitor to give support and voltage reduction. The regulated current source can be employed to achievecharge control in ES, according to Equation (2). As a result, an electric spring can be represented as a voltage source controlled by current.

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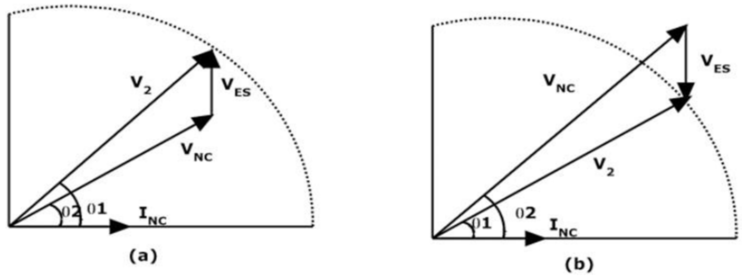

Fig 4. Phasor diagram of Electric Spring (a) inductive mode (b) capacitive mode

The ES in series connection is used to adjust voltage at the connecting point where the device is connected Vin to the reference value Vinref. The critical load is connected in parallel with SL, which consists of ES and noncritical load, as indicated in Fig 2. V2 is the voltage across it. Electric springs can also be used to balance both active and reactive power. [15] gives a brief description of the ES design. To make an electric spring lossless, the compensation voltage Ves must be in quadrature with the noncritical load current Io. There are three different modes of operation for ES: voltage support, voltage suppress, and neutral mode [2]. For a resistive-inductive load, Ves must be 90° ahead of INC and offer capacitive compensation, but for a resistive capacitive load, Ves must be 90° behind INC and provide capacitive compensation. When compared to older FACT devices like SVC and STATCOM, which only manage pure reactive power, the ES, which is a novel smart-grid technology, can support both active and reactive power. The voltage at PCC is equal to the vector sum of noncritical load voltage VNC andES voltage VES, as shown in Fig 4.

The injected voltage and the NCL impedance are both used in ES reactive power injection. Take a look at Fig 2 foran example of a circuit. Both ES and SL inject the same amount of reactive power into a purely resistive type NC load. ES functioning in voltage support mode (capacitive) for RL type load,

$$V_2^2 = (V_{NC} - V_{ES}\, sin\theta_2)^2 + (V_{ES}\, cos\theta_2)^2 \qquad (4)$$

$$V_{NC} = \pm\sqrt{V_2^2 - (V_{ES}\, cos\theta_2)} + V_{ES}\, sin\,\theta_2 \qquad (5)$$

$$Q_{ES} = V_{ES}\, I_{NC}\, sin(-90) = -V_{ES}\, I_{NC} = -(V_{ES}\, V_{NC}) / Z_L \qquad (6)$$

$$Q_{NC} = V_{NC}\, I_{NC}\, sin\theta_2 = (V_{NC}^{\ 2}\, sin\theta_2) / Z_L \qquad (7)$$

Where $V2$ is basic burden voltage,

QES is ES responsive power and

QNC is receptive power of NCL.

From the above conditions entire responsive power of the smart load QSL acquired by summing equation(6) and (7) ,is given

$$Q_{SL} = Q_{ES} + Q_{NC} \qquad (8)$$

$$Q_{SL} = [-V_{ES} (\pm\sqrt{V_2^2 - (V_{ES}\, cos\theta_2)} + V_{ES}\, sin\,\theta_2) / Z_{NC}] + \{[(\pm\sqrt{V_2^2 - (V_{ES}\, cos\theta_2)} + V_{ES}\, sin\,\theta_2)^2\, sin\theta_2] / Z_{NC} \} \qquad (9)$$

Likewise, for ES in voltage suppress(inductive)mode comparing voltage across NCL and responsive power of SL can besummed up as

$$V_{NC} = \pm\sqrt{V_2^2 - (V_{ES}\, cos\theta_2)} - V_{ES}\, sin\,\theta_2 \qquad (10)$$

$$Q_{SL} = [-V_{ES} (\pm\sqrt{V_2^2 - (V_{ES}\, cos\theta_2)} + V_{ES}\, sin\,\theta_2) / Z_{NC}] + \{[(\pm\sqrt{V_2^2 - (V_{ES}\, cos\theta_2)} + V_{ES}\, sin\,\theta_2)^2\, sin\theta_2] / Z_{NC} \} \qquad (11)$$

Furthermore, the above conditions clearly show that ES responsive power is dependent on the NC burden impedance. As a result, the magnitude of NC and C loads have an impact on ES activity.

V. CONTROL SCHEME OF SMART LOAD

The proposed ES-based SLs methodology is modelled to reduce voltage flickering at the load terminal caused by irregular power generation. The schematic control diagram for ES in distinct phase for demand side management and voltage regulationis shown in Fig 2. Fig 5 depicts the control circuit. In this model, the dynamic changes at the DC link, as well as the resulting losses, are neglected. As a result, the electric spring will only exchange reactive energy with the grids. Through decoupling, the reference value signal for the PWM inverter is derived from the scalar value of the modulation index and the phase of the sine wave. By comparing the CL voltage (rms) Vs with the reference nominal voltage Vsref, the modulation index, m, is obtained. The phase of the noncritical load current is determined using PLL. The leading or lagging phase angle with a 90-degree change, depending on noncritical load characteristics. As a result, the reference value signal will be as follows:

$$V_{PWM\ ref} = m \sin(\omega t+\theta) \qquad (12)$$

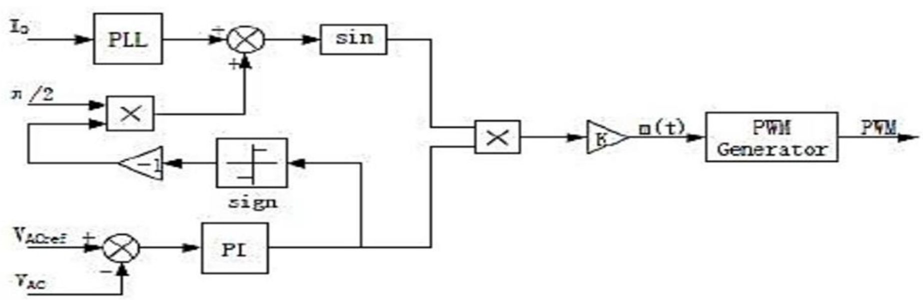

Fig 5. Control Block of Electric spring

VI. CASE STUDY

A. The 15 Bus Sytem With Integrated Pmsg Wind Energy System

Swaying in generated power and dynamic power transferred by GSC is expected to occur because of variations in windspeed. Huge interruptions in grid power (Pg and Qg) are also documented as a result of the susceptibility of wind-generatedpower. At the load bus, the heap impedances (ZLs and ZLc) are assumed to be constant. The x-axis on the SIMULINK model outputs represents time in seconds, while the y-axis represents wind power (P) and Rms voltage (Vrms). Due to the transition period, there is no increase in power from 0 to 1 second, and from 1 second to 10 seconds, the wind power output is 1.52 MW, with a voltage of 2430V at the load bus.

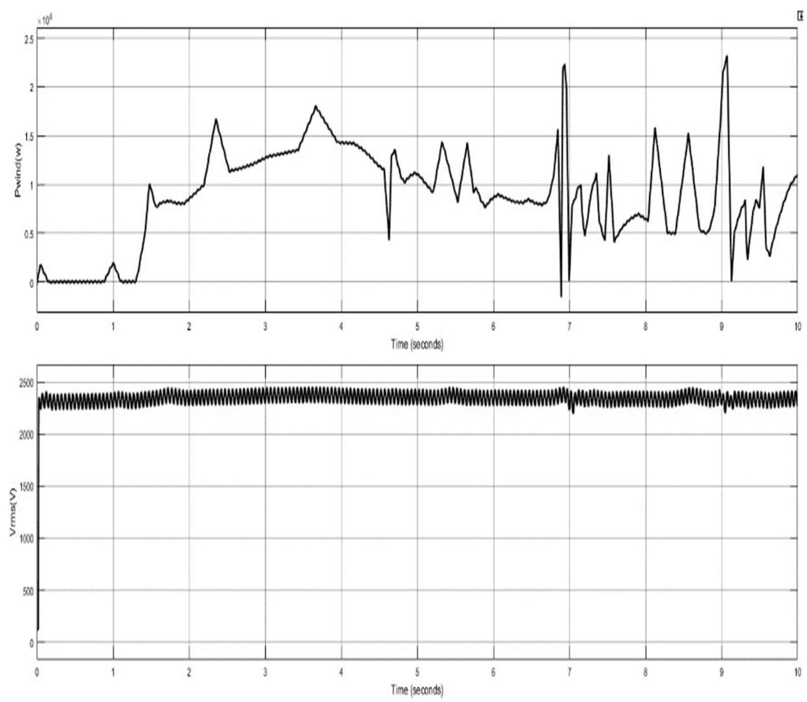

Fig 6.Test result of PMSG wind generated power and voltage at load bus of 15 Bus system

B. 15 Bus Distribution System With ES And STATCOM

A voltage source framework is used to handle the mass power framework. A regulated current infusion at the associating point with the framework is used to frame the genuine and responsive power variety due to a sustainable power supply. Theactivity of the shrewd burden regulator is dependent on the controls on voltage infusion by the electric spring in relation tothe noncritical burden.

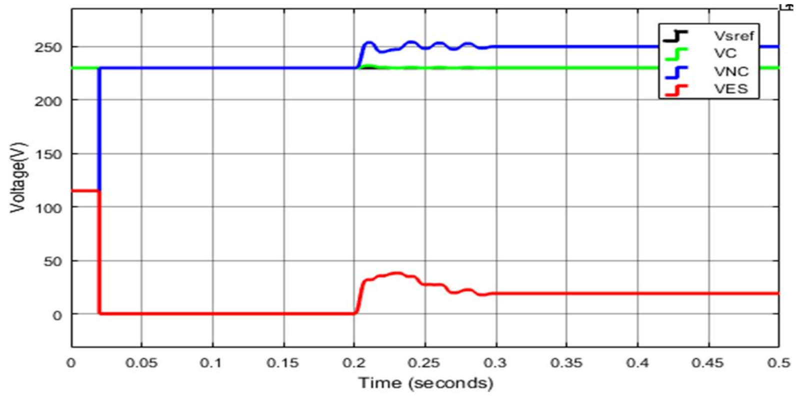

Fig 7. System response following overvoltage condition with resistive type Critical load and Noncritical load of 15 Bussystem

Figure 7 depicts the framework reaction in an overvoltage state when ES is connected in series with a totally resistive NCL. The yield acquired reveals that the reference voltage is 230V, the critical voltage is 230V, the noncritical voltage is 250V, and the electric spring voltage is 20V, with the x-axis displaying the time and the y-axis displaying the Voltage(V).

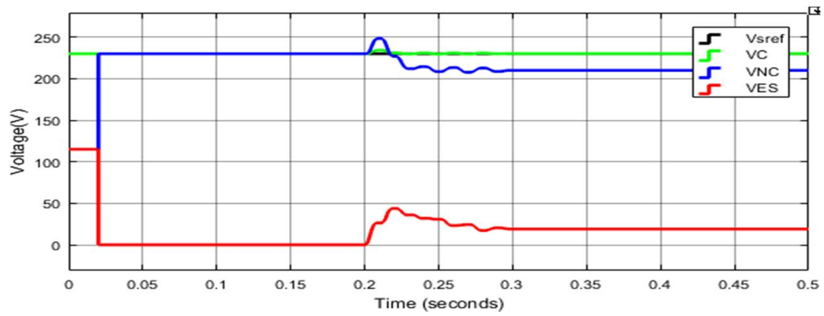

Fig 8. System response following under voltage condition with resistive type Critical load and Noncritical load of 15 Bussystem

Figure 8 shows how ES is used to regulate voltage across CL in an undervoltage situation. The yield obtained is shown as 230V reference voltage, 230V critical voltage, 210V noncritical voltage, and 20V electric spring voltage.

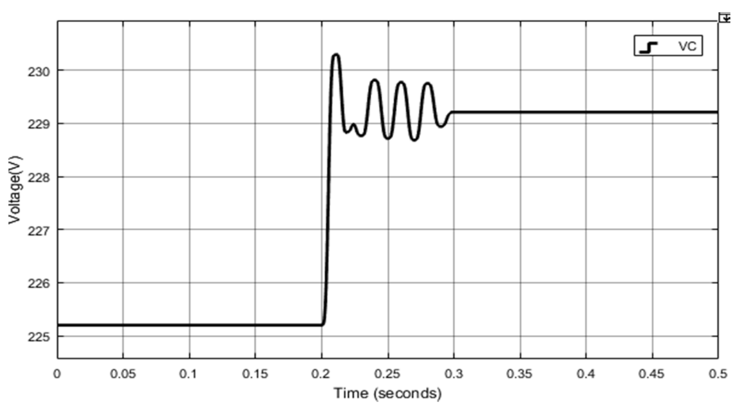

Fig 9. Voltage across critical load with RL type noncritical load of 15 Bus system

For a resistive-inductive(R-L) type noncritical load, the voltage across the critical load is displayed in figure 9 when the electric spring is working in voltage support(i.e., capacitive) mode and from the diagram, the x-axis shows the time in short order andthe y-axis shows the Voltage(V) the critical voltage acquired is 229.3V.

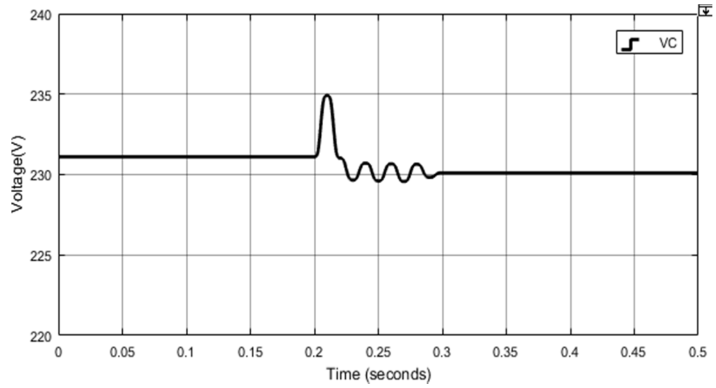

Fig 10. Voltage across critical load with RC type noncritical load of 15 Bus system

When the electric spring is working in voltage suppress(i.e., inductive) mode for a resistive-capacitive(R-C) type noncritical load, the voltage across the critical load is displayed in figure 10, The ctitical load voltage acquired is 233V.

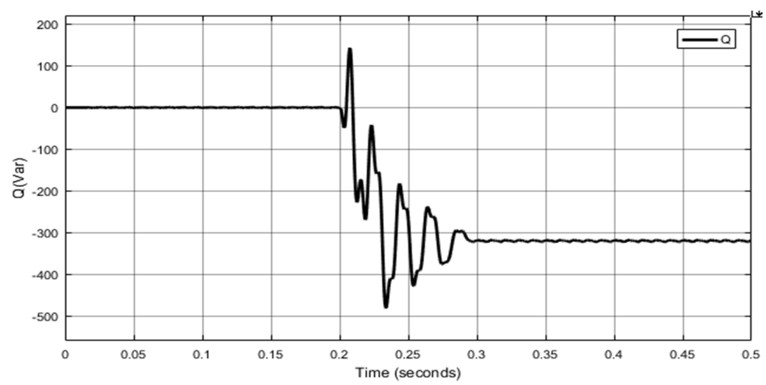

Fig 11(a). Change response of reactive power in inductive mode with Electric spring of 15 Bus system

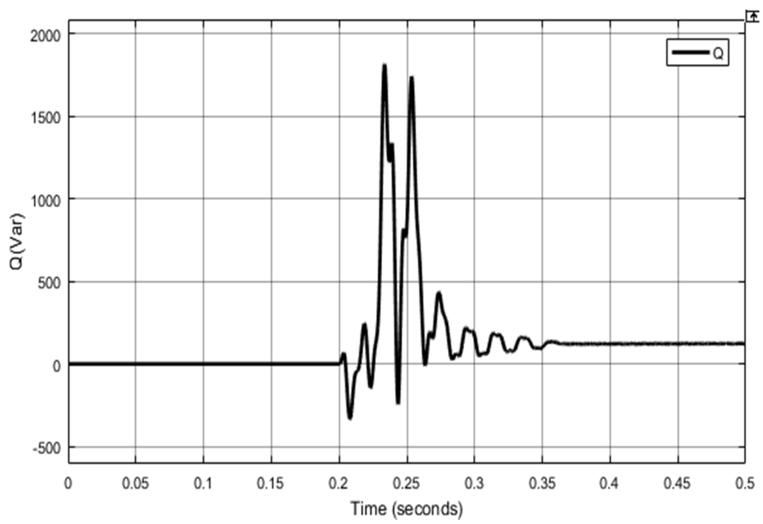

Fig 11(b). Change response of reactive power in inductive mode with STATCOM of 15 Bus system

The responsive power assimilated in inductive mode with Electric spring is 310 VAr, and the receptive power retained in inductive mode with STATCOM is 120 VAr, as shown in Figs 11(a) and 11(b). The x-axis indicates the time and the y-axis indicates the Q (VAr).

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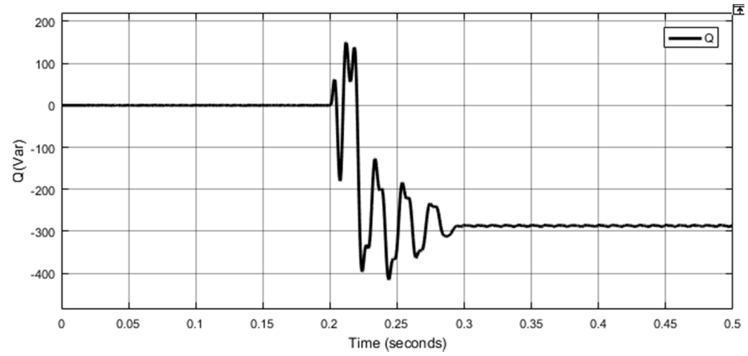

Fig 12(a). Change response of reactive power in capacitive mode with Electric spring of 15 Bus system

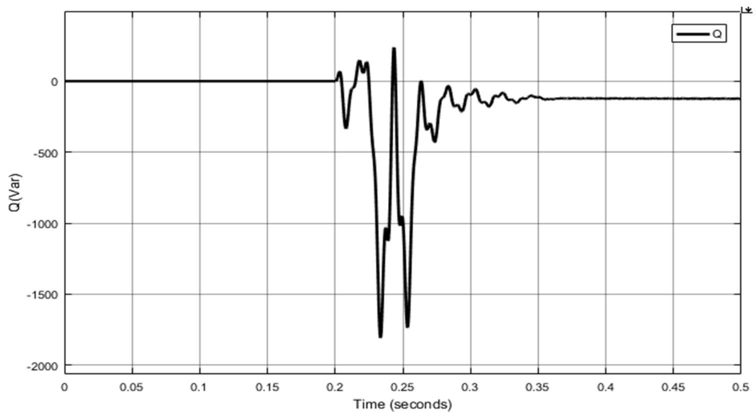

Fig 12(b). Change response of reactive power in capacitive mode with STATCOM of 15 Bus system

From figure 12(a) and 12(b), It can be deduced that thereceptive power maintained in capacitive mode with Electric spring is 130 VAr, while the responsive power used in capacitivemode with STATCOM is 290 VAr.

VII. DISCUSSIONS

Table 4 Comparison Of 3 Bus And 15 Bus System

	3 Bus System Values [1]	15 Bus System Values
Generated power when the system is integrated with PMSG wind energy system	P = 1.46MW	P = 1.52MW
Voltage at load buswhen the system is integrated with PMSG wind energy system	V = 2364V	V = 2430V
System response following overvoltage condition with resistive type Critical load and Noncritical load	Vref = 230V Vcl = 230V Vncl = 210V Ves = 115V	Vref = 230V Vcl = 230V Vncl = 250V Ves = 20V
System response following undervoltage condition with resistive type Critical load and Noncriticalload	Vref = 230V Vcl = 230V Vncl = 250V Ves = 115V	Vref = 230V Vcl = 230V Vncl = 210V Ves = 20V

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Voltage across critical load with RL type noncritical load	V = 226V	V = 229.3V
Voltage across critical load with RC type noncritical load	V = 233V	V = 233V
Change response of reactive power in inductive mode with Electric spring	Q = 320VAr	Q = 310VAr
Change response of reactive power in inductive mode with STATCOM	Q = 220VAr	Q = 120VAr
Change response of reactive power in capacitive mode with Electric spring	Q = 210VAr	Q = 130VAr
Change response of reactive power in capacitive mode with STATCOM	Q = 370VAr	Q = 290VAr

From the comparison table it is clear that,

- In Inductive mode, if a drop in bus voltage occurs, both the electric spring and the STATCOM supply responsive power tothe framework, with the electric spring absorbing roughly 100VAr more than the STATCOM in both the 3 bus and 15 bus frameworks. The responsive power required by the electric spring to maintain the fundamental burden voltage at reference esteemis more than the responsive power required by STATCOM for a comparable task. Q (ES) = 320VAr and Q (STATCOM) = 220VAr for a three-bus system.[1]Q (ES) = 310VAr and Q(STATCOM) = 220VAr for a 15-bus system.
- In the event of a drop in bus voltage, both the electric spring and the STATCOM contribute reactive power to the system, with the electric spring requiring around 150VAr less than the STATCOM in both the 3 bus and 15 bus systems. Because an increase in electric spring voltage reduces noncritical load voltage, active power consumption across noncritical loads is reduced. Q (ES) = 210VAr and Q (STATCOM) = 370VAr for a three-bus system.[1]Q (ES) = 130VAr and Q(STATCOM) = 290VAr for a 15-bus system.

As a result, as compared to STATCOM to reestablish the bus voltage, the responsive power supply to the framework usingElectric spring is less.

Clearly, the voltage variation is appropriately received by Electric spring, as shown by the preceding discussion. In this attempt, the effects of receptive power variation and DC connect modifications are taken into account. This feature, along with the ability to manage both dynamic and reactive power, bolsters the argument that electric springs are adaptable devices for maintaining stability in microgrids with integrated environmentally friendly power systems and less dependence on communication developments.

The relationship between voltage control execution using ES and the STATCOM for a 3 Bus and 15 Bus framework has been accomplished. For a certain range of voltage fluctuation, absolute voltage regulation and the total responsive limit supplied for desired voltage guideline are considered. According to the findings, ES requires smaller receptive power limit than STATCOMand provides better framework voltage management. As a result, responsive remuneration using ESs-based innovation becomes a comforting innovation for future intelligent frameworks, where voltage guidance for sensitive loads would be a great test alongside request side response.

VIII. CONCLUSION

This paper examined proposition of the ES based burdens for a 3 bus framework and 15 bus framework which is for load on dispersion framework with high infiltration of RPGs. The target incorporates moderation of voltage gleam because of discontinuity of RPGs and giving receptive power pay. Displaying and plan for a H-bridge converter type ES have been introduced for framework voltage guideline at matrix side. The standard and working of the Electric spring (ES) with DC- interface capacitors are examined. And furthermore correlation concentrate on directed with respect to voltage control abilityof ES against the conventional FACTS gadget such as STATCOM. The absolute voltage guideline, and all out receptive limit needed for wanted voltage guideline for a scope of voltage variation are looked at.

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The control signal plan for receptive power remuneration and mains voltage guideline by ES was proposed and acknowledged likewise execution of the SLs was examined on test feeder. It is presumed that for 3 bus and 15 bus power framework ES can give voltage guideline, concealment, and burden the board capacities with the shifting necessities of the power network. It can be seen as an alternative that ES can be a helpful gadget for the dependability control, which is the excellent prerequisite for future savvy network with expanded infiltration of irregular environmentally friendly power sources.

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