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Implementation of 3-Phase Electric Springs in Unbalanced Power Systems using Instantaneous Power Theory

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Abstract - *These projects implement the criteria and conditions for minimizing the average and oscillating power of the three phase Electric Spring (ES).The proposed process for providing multiple control objectives of voltage regulation and power balancing of the 3-ph power system, and minimization of the average and oscillating ac power of the ES. A corresponding control scheme implementable in a single controller is included and explained. The control scheme has been practically verified with experiments.*

***Key Words*: Electric Spring(ES), Programmable Integral Controller(PIC), Analog to Digital Converter(ADC).**

1.INTRODUCTION

Power imbalance is a common and critical power quality issue in 3-ph power systems. Mild imbalance can be caused by unbalanced loading or asymmetrical grid impedance, while severe short-term imbalance can be caused by power system faults. Power imbalance can result in a variety of undesirable phenomena on both power systems and equipment, such as overheating on induction motors, large power loss, significant neutral current, poor power quality, and tripping of power converters or generators. Solutions to tackle power imbalance have evolved from passive approaches to active approaches. Conventionally, passive filters (PFs) are used to replace bulky and expensive 3-ph to 2-ph transformers or rotating equipment. However, PFs are incapable of eliminating time-varying harmonic contents. The development of power electronic switches gives rise to active filtering techniques. Due to their fast responses, active filtering techniques (such as static var compensator (STATCOM), series- and shunt-type active filters (AFs), and bi-directional unified power quality conditioner (UPQC) [3]) have grown into the mainstream solutions in addressing power imbalance and harmonic issues, at the expense of high costs and complex structures.

A variety of control methods have been introduced including 1) redistributing real power among three phases for power balance, 2) providing reactive power and harmonic compensation to achieve unity power factor, and 3) compensating positive-, negative-, and zero-sequence components separately or jointly. Although these technologies can provide satisfactory compensation outcomes on various power quality issues, new methods are needed to address the challenges of emerging power grids fed by increasing penetration of renewable energy source (RES). In the regime of RES control, there is an interest in using power electronic interfaces to mitigate the adverse impact of unbalanced grid conditions. Based on instantaneous power theory, different control methods have been proposed to limit peak current, provide voltage support, improve current waveform, and remove power oscillation.

Although these ancillary services of RESs are valuable additions to the main function of power conversion, their availability highly depends on the disposable capacity of power converters and the accommodation of different control targets. Alternatively, energy storage is a useful but expensive technology. Traditional demand-side management (DSM) enables “load demand following power generation” but does not offer power regulation in an instantaneous manner. With a response time in the order of milliseconds, electric spring (ES) has recently been introduced as a fast and effective DSM technology to solve various power quality issues including voltage regulation frequency stabilization, and power quality improvement. 3-ph ES system andts control are reported. The combined use of energy storage, 3-ph ES, and non-critical loads allows a 3-ph ES to process a substantial amount of active power with reduced storage capacity in addition to its inherent reactive power compensation.In the original implementation in the solutions of the complicated system equations are solved numerically by genetic algorithm for the ES to perform voltage regulation and current balancing. Naturally, the ES voltage references are near-optimal. Later, significant progress has been made in where a theory has been developed to find the exact analytic solution of using the 3-ph ES for mitigating power imbalance in a 3-ph power supply. This theory also allows the use of the differences of the active power in the three phases to restore the power balance with minimum energy storage of the battery. Based on the Instantaneous Power Theory, this project further extends the research of 3-ph ES to achieve multiple objectives of voltage regulation, reduction of power imbalance and also minimization of the oscillating active power that is not previously explored. It is found that the Instantaneous Power Theory provides a good theoretical framework for analyzing and optimizing the 3-ph power supply with ES and smart loads installed. In this paper, the performance of the 3-ph ES is improved in two critical aspects. Firstly, the multifunctional control is proposed to enable the multitasking of 3-ph ES. The key functions of voltage regulation and current balancing can be enacted simultaneously.

Secondly, the active power optimization of 3-ph ES is addressed in a general case where both source voltages and currents are unbalanced. The adoption of instantaneous power theory and sequence analysis provides an accurate description of the power feature of 3-ph ES. Based on this, the proposed optimization method can not only minimize average active power but also dampen the oscillating active power. Experimental results demonstrate that the proposed multifunctional control and active power optimization are quite effective in improving the performance of 3-ph ES.

1.1 ELECTRIC SPRING

Electric Spring, 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.To improve voltage regulations, stability and power factor in ac transmission and distribution systems and how the reactive power affects power system operations, the challenges to voltage control in power systems and to provide background information on the mathematical challenges associated with voltage control and reactive power supplied. This paper presents an energy efficiency comparison of the electromagnetic and electronic ballast systems under both full power and dimming conditions. for controlling the output from individual DG's that were installed in micro grid the author developed an energy control system because as we know that DG's uses an renewable energy sources have an unstable output and this can negatively affect existing electric power system. To control the active power supplied by distributed generation system while compensating harmonics and reactive currents caused by nonlinear loads using shunt active power filter.

The earlier technology shows that the traditional series reactive power compensators use output voltage control for a reactive power controller, but the proposed technology demonstrate characteristics different(input voltage control) from traditional devices such as series reactive power controller.

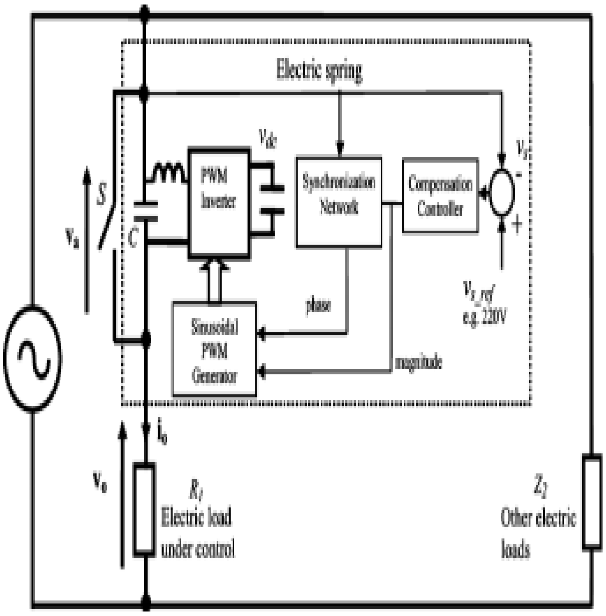

Fig1.1: Control Block Diagram of Electric Spring

The effects of this subtle change of control methodology and the interactions between the electric springs and energy storage in a power grid, which have not been previously addressed. Unlike STATCOM, Static VAR Compensation, and UPFC technologies, electric springs offer not only reactive power compensation, but also automatic load variation in non-critical loads (with electric springs embedded). The main contributions of this paper are:a) MATLAB simulation model of Electric spring for single phase circuit. b) Analysis of the different modes of operation of ES circuit. c) Implementation of Electric Spring Simulink model for 3 phases system. d) Operation of Electric Spring circuit during power fluctuation due to renewable energy source is examined. e) Analysis the different results of circuit when connected to 3 phase system. The rest of paper is organized as follows. The overview of some basic concepts and formulae, control strategy and different operating modes; It contains implementation of spring circuit for 3 phase system; section IV contains simulation results and discussion of different cases. Conclusions are summarized.

1.2 INSTANTANEOUS POWER THEORY

The instantaneous active and reactive power theory, or the so-called "p-qTheory". Then, the need for a consistent set of power definitions is emphasized to deal with electric systems under non-sinusoidal conditions. Then, it has been extended by the authors of this book, as well as other research scientists. This book deals with the theory in a complete form for the first time, including comparisons with other sets of instantaneous power definitions. The usefulness of the p-q Theory is confirmed in the following chapters dealing with applications in controllers of compensators that are generically classified here as active power line conditioners. The term "power conditioning" used in this book has much broader meaning than the term harmonic filtering." In other words, the power conditioning is not confined to harmonic filtering, but contains harmonic damping, harmonic isolation, harmonic termination, reactive-power control for power factor correction, power flow control, and voltage regulation, load balancing, voltage-flicker Suction, and/or their combinations. Active power line conditioners are based on leading-edge power electronics technology that includes power conversion circuits, power semiconductor devices, analog/digital signal processing, voltage/current sensors, and control theory. Concepts and evolution of electric power theory are briefly described below. Then, the need for a consistent set of power definitions is emphasized to deal with electric systems under non-sinusoidal conditions. Problems with harmonic pollution in alternating current systems (ac systems) are classified, including a list of the principal harmonic-producing loads. Basic principles of harmonic compensation are introduced. Finally, this chapter describes the fundaments of power flow control. All these topics are the subjects of scope, and will be discussed deeply in the following chapters of the book. The instantaneous power theory, or "the p-q theory," makes clear the physical meaning of what instantaneous real and imaginary power is in a three-phase circuit. Moreover, it provides insight into how energy flows from a source to a load, or circulates between phases, in a three-phase circuit. This theory can be used in the design and understanding of FACTS (Flexible AC Transmission System) compensators. The book introduces many concepts in the field of active filtering that are unique to this edition. It provides a study tool for final year undergraduate students, graduate students and engineers dealing i-th harmonic pollution problems, reactive power compensation or power quality in general.

2 EXISTING SYSTEM

In Existing system the three phase power is controlled by the controller called statcom. The Statcom controller allows to control negative sequence current flow and to rebalance distribution system voltages without requiring any net real power from the compensator. With increasing penetration of intermittent and distributed renewable energy sources such as wind and solar power, there has been rising concern on power system stability. To address those issues, many demand-side management techniques have been proposed to ensure the balance between power generation and consumption. Such techniques include: i) scheduling of delay-tolerant power demand tasks; ii) use energy storage to compensate peak demand; iii) real-time pricing; iv) direct load control or on-off control of smart load. Energy storage is a valid solution to cope with the instantaneous balance between power supply and demand. However, costs and limited energy storage capacity of batteries are practical issues. Therefore, new solutions that can reduce energy storage are preferred. Electric Spring (ES) is a new smart grid technology that can provide electric active suspension functions for voltage and frequency stability in a distributed manner for future smart grid. Based on Hooke's law, ES has been practically realized with power electronic circuits for improving both voltage and frequency stability in micro-grid hardware simulator. The same functions for voltage and frequency stability have also been successfully evaluated in a simulation study for a So far, three versions of ES have been conceived.

Power electronics, being an enabling technology, can offer new solutions to the stability control of future smart grid with substantial penetration of distributed and intermittent renewable energy generation. Based on the three-century old Hooke's law for mechanical springs, electric springs (ESs) have recently been proposed and successfully developed as a new smart grid technology for stability control in power grid and for achieving the new control paradigm of load demand following power generation. The initial concept of the ESs for reactive power compensation has been described. However, further research has indicated that the full potential of ESs has not been explored. In this paper, a steady-state analysis and control principle of ESs for both active and reactive power compensations are presented. A range of active and reactive power compensation modes for typical loads of resistive, inductive, and/or capacitive nature which ESs can support are described. These compensation modes of the ES have been practically verified with experimental prototypes.

Wind power has emerged as one of the most dominant renewable source of Energy with immense growth potential across the globe. The new global total capacity at the end of 2012 was 282.5GW & annual installed capacity of various region of the globe. The development of modern wind power conversion technology has been going on since1970s, and the rapid development has been seen from 1990s. The early technology used in wind turbines was based on squirrel cage induction generators (SCIGs) directly connected to the grid. Recently, the technology has developed toward variable speed. Environmental problem has become more and more severe all over the word. Air pollution legislations have been drafted and plans are made to raise the proportion of renewable power sources by many countries. With more and more intermittent renewable power sources such as wind energy, the stability of power grid becomes a big issue. The key problem of instability is the mismatch between power generation and load demand.

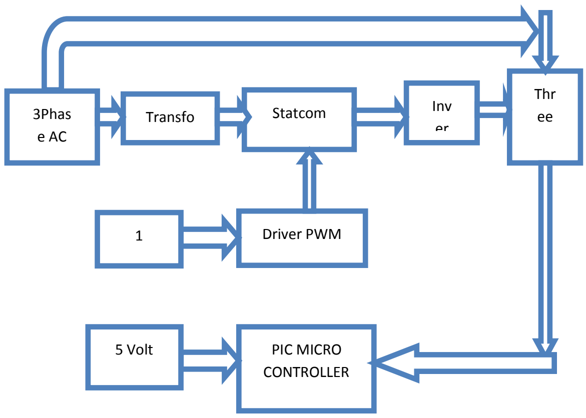

Fig 2.1: Block Diagram of Existing System

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In the fundamental working principles and practical implementation of the first generation of ES (i.e. ES-1) with capacitive storage have been reported. By working under inductive and capacitive mode, ES-1 is capable of regulating the mains voltage to its nominal value in the presence of intermittent power injected into the power grid. With input voltage control, ES can work with non-critical loads that have high tolerance of voltage fluctuation (e.g. with operating voltage range from 180 V to 265 V for a nominal mains voltage of 220 V). Examples of the non-critical loads are thermal loads such as ice-thermal storage systems, electric water heater systems, air-conditioning systems and some public lighting systems.The first version of ES provides only reactive power compensation for mains voltage regulation and simultaneously varies the non-critical load power so as to achieve automatic power balancing within the power capability of the ES and its associated non-critical load. This arrangement allows ES-2 to work in eight different operating modes and to provide both active and reactive power compensation. It also enables ES-2 to perform extra tasks such as power factor correction and load compensation. The first and second versions of ES are illustrated in (a) and (b), respectively.

With many countries worldwide determined to decarbonize electric power generation within the next few decades, new concerns about power system stability have arisen from the increasing use of intermittent renewable energy sources. Due to the distributed and intermittent nature of renewable energy sources, such as wind and solar energy, power companies will find it impossible to instantaneously predict and control the total power generation in the entire power grid. Future smart grid requires a new control paradigm that the load demand should follow power generation, which is just opposite to existing control method of power generation following load demand.

3. PROPOSED SYSTEM

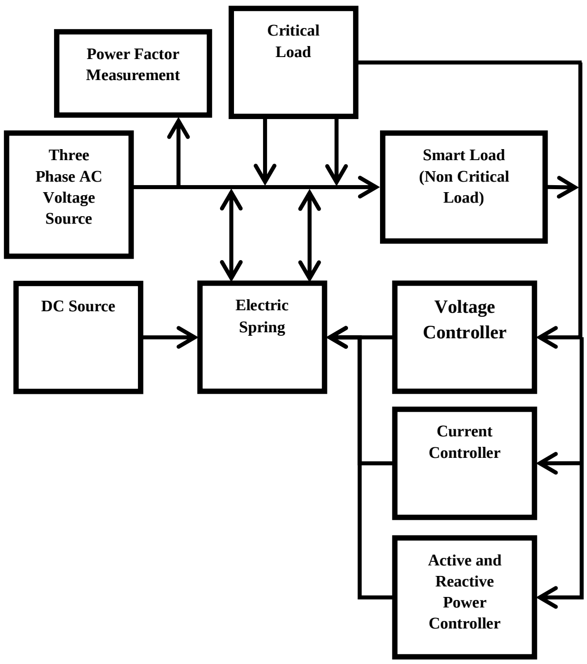

Fig 3.1: Block Diagram of Proposed System

The ES are serially-connected to a non-critical load as a smart load. The proposed system is works on both AC and DC and associate with NCL and CL loads. Electric springs(DC-ES) for bus voltage stabilization and power balancing in DC grids is reported. The proposed control strategy is to change voltage control to direct current control, which needs a controlled current source.PID control scheme is implemented for both load and source demand side management. The proposed control strategy is to change voltage control to direct current control, which needs a controlled current source. The ES with CSI in proposed which can be regarded as a current controlled current source (CCCS). The current control where the ES is substituted by a CCCS designated and the branch with line impedance is replaced by a current source designated. ES has to generate an ac current to compensate the fluctuations in the input current to achieve a stable CL voltage. In order to ensure that the power inverter acts as a purely reactive power controller, the vector of the current through the electric spring and the vector of the voltage across the electric spring should be ideally perpendicular to each other. A power transformer supplies electricity to many houses in a residential area, the mains voltage nearest the transformer may be 230 V (which is the nominal voltage) and that farthest from the transformer would be lower than 230 V (e.g., 210 V), because of the voltage drop along the distribution feeder. But it maintains 230v ac constant voltage**.**

Three-phase electric power is a common method of alternating current electric power generation, transmission, and distribution. It is a type of polyphase system and is the most common method used by electrical grids worldwide to transfer power. A transformer is a static electrical device that transfers electrical energy between two or more circuits. A varying current in one coil of the transformer produces a varying magnetic flux, which, in turn, induces a varying electromotive force across a second coil wound around the same core. Electrical energy can be transferred between the two coils, without a metallic connection between the two circuits. A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC). The input voltage, output voltage and frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power; the power is provided by the DC source. The use of "Electric Springs" is distributed voltage control through voltage compensators connected in series with individual noncritical loads that are less sensitive to voltage fluctuations.

These compensators inject a series voltage in quadrature (either lead or lag) with the current flowing through them in order to regulate the voltage across the point of common coupling where critical (i.e., voltage sensitive) loads are connected. The use of "Electric Springs" is a recently introduced approach to distributed voltage control through voltage compensators connected in series with individual noncritical loads that are less sensitive to voltage fluctuations. These compensators inject a series voltage in quadrature (either lead or lag) with the current flowing through them in order to regulate the voltage across the point of common coupling where critical (i.e., voltage sensitive) loads are connected.

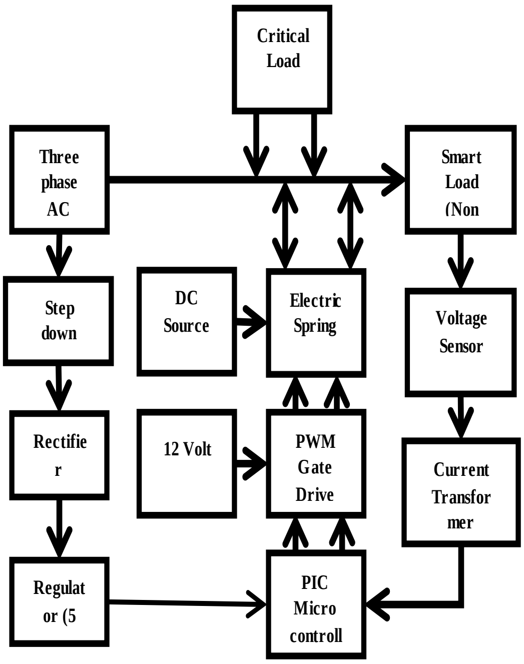

Fig 3.2: Hardware Block Diagram

3.1 ES IN A SMART LOAD

An overview of the concept of smart load that comprises an ES and the actual load Z. The ES is a power electronic interface that generates an ac voltage profile V_{ES} (t) to act as a series compensator to modify the applied voltage of the actual load vo (t), thus directly affecting the composition of real and reactive powers flowing to the load.

It can be embedded in electric appliances, forming a new generation of smart loads adaptive to the power grid. When massively distributed over the power grid, they could provide highly distributed and robust support for the smart grid, similar to the arrays of mechanical springs supporting the mattress. The smart load is connected to an ac power source with vs (t), which may represent a strong or a weak power source on a grid network with or without transmission impedance. In this study, we adopt the general assumption that both the power source and the load are capable of bidirectional power flow, meaning that they can both act as power source (negative resistive) or power sink (resistive). The instantaneous voltage equation of this system is

$$v_s(t) = v_o(t) + v_{es}(t)$$

These differences from a series RPC offer many beneficial features for the ES:

i) the line voltage can be supported to nominal value, giving the critical load a stable voltage

ii) the non-critical load connected in series with ES can consume the fluctuating power generated by the unstable AC power sources.

Such useful properties of allowing instantaneous balance of power supply and demand while concurrently achieving local line voltage stability is particularly useful and important for future smart grids with a large penetration of renewable energy resources. Moreover, with the ES connected in series with the noncritical load Zo, controlled variation in power consumption is easily achievable. Non-critical loads such as water heaters, air-conditioning systems, public lighting systems, and refrigerators can be varied or shed off, as and when necessary. The advantages of this arrangement are twofold. Firstly, the ES can be a small-capacity compensator embedded in common electrical appliances that are widely present in a distributive manner. Secondly, by keeping the local line voltage stable and letting the output of the ES to fluctuate, the non-critical loads can absorb the fluctuating power while ensuring a constant voltage supply to the critical loads.

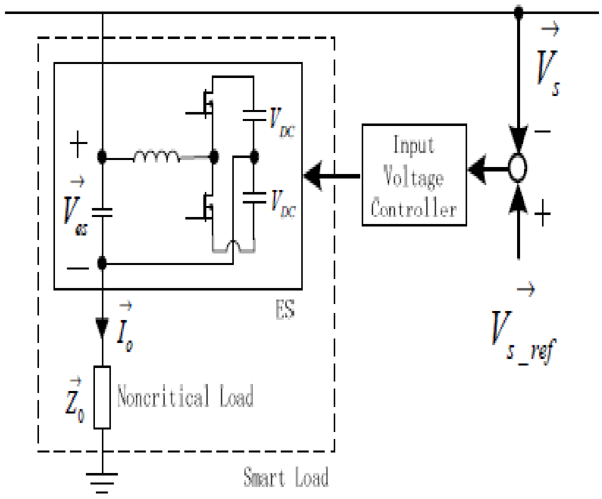

Fig 3.3:Use of ES in electrical system

4. SOFTWARE REQUIREMENTS

MATLAB (matrix laboratory) is a fourth-generation high-level programming language and interactive environment for numerical computation, visualization and programming. MATLAB is developed by Math Works .It allows matrix manipulations; plotting of functions and data; implementation of algorithms; creation of user interfaces; interfacing with programs written in other languages, including C, C++, Java, and Fortran ;analyze data; develop algorithms; and create models and applications. It has numerous built-in commands and math functions that help you in mathematical calculations, generating plots and performing numerical methods.

4.1 MATLAB's Power of Computational Mathematics

A simple communication system contains three parts: the transmitter, the channel (the transmitting medium), and the receiver. The information source and information sink are also considered part of the communication system.

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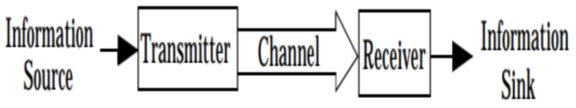


Fig 4.1: General block

The task of communication system engineers is to design and maintain a communication system such that the receivers can correctly demodulate, decode, and correct errors in the transmitted message. In general, a communication system can be classified as either analog or digital. A transmitter for an analog communication system may include signal modulation and multiple access. Multiple access is a "sharing" technique whereby signals are sent in turn. A receiver for an analog communication system may include a signal filtering bank and signal demodulation.

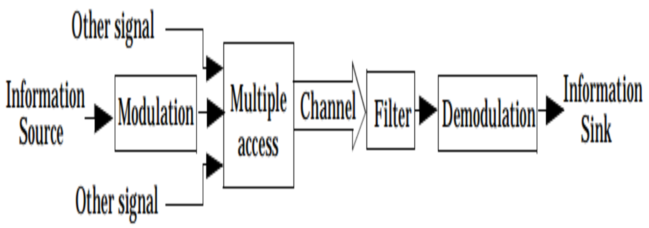


Fig 4.2: Multiple access blocks

The messages in a digital communication system are represented by using digital numbers or bits.A transmitter for a digital communication system may include source coding, data compression, error-control coding, digital modulation, and multiple access. Source coding is a process using a digital signal to represent an analog signal. Data compression is a process that converts the message into a compressed message, meaning a message that has fewer information bits than the original message.

The receiving side can recover the original message from the compressed message by a data decompression process. Error-control coding adds redundant error-checking and/or error-correction bits. The receiving side can use the extra bits to detect and/or correct the transmission errors. Digital modulation maps the digital signal to an analog signal and then uses a higher frequency signal to carry the analog signal. This figure shows the parts of the transmission process.

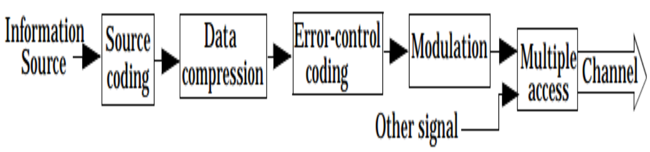


Fig 4.3: Transmitter control

A receiver is conceptually the inverse of the transmitter. In most cases, the receiving process method should match exactly the transmitting process method to recover the transmitted message. This figure shows the parts of the receiving process.

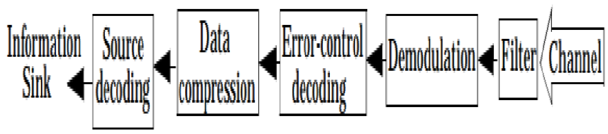


Fig 4.4: Receiver control

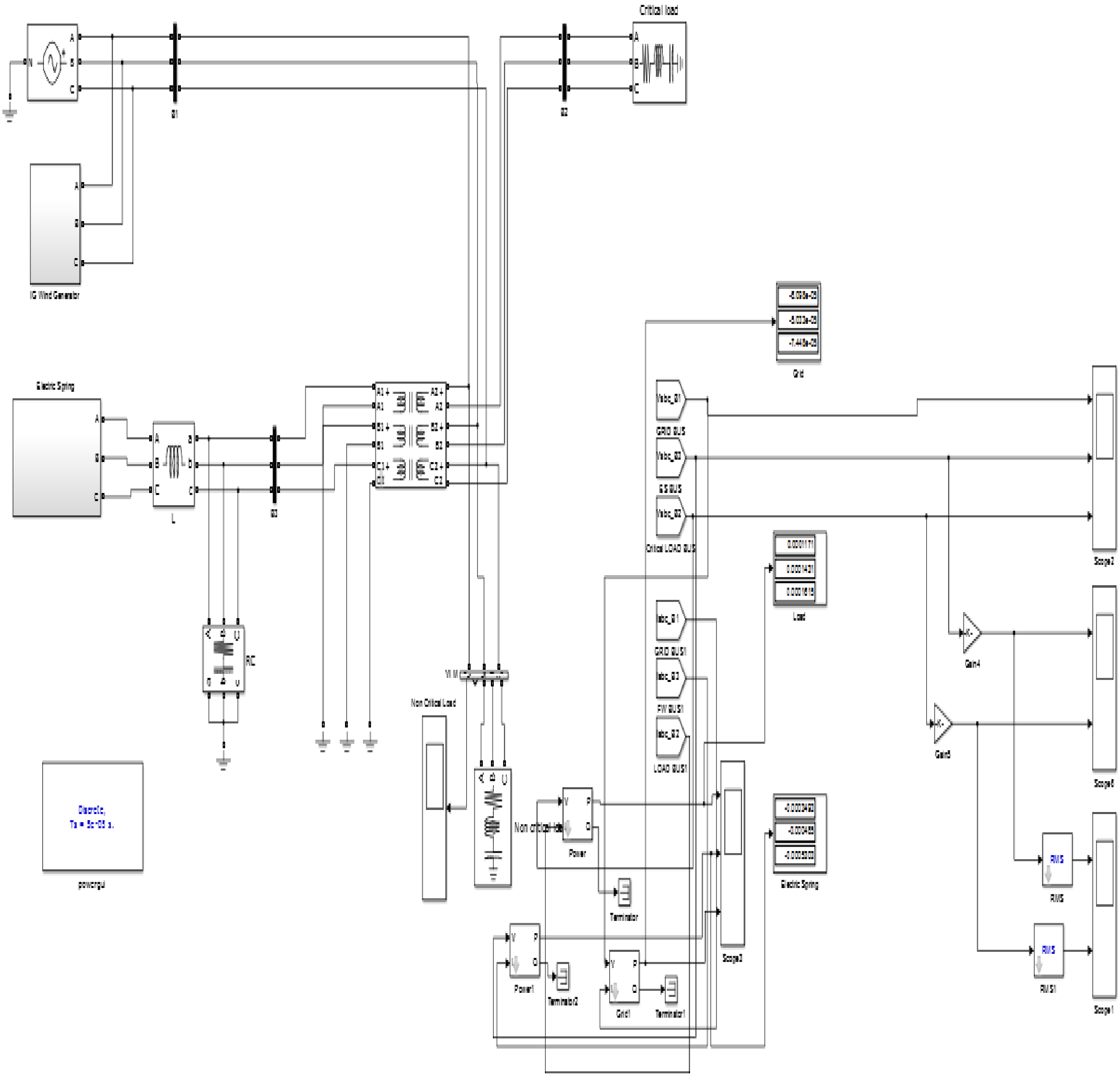
The channels in communication systems may vary in different applications. In general, a channel may introduce noise, fading, phase shifting, and interference to the transmitted signal. The techniques used in the digital communications field are also used in other applications. For instance, source coding, data compression, and error-control coding techniques are widely used in computer storage applications. Except for data compression, this toolbox provides ready-to-use tools to design, analyze, and simulate communication systems. These systems include both analog and digital communication systems.

4.2 Model- Based Design

Model-Based Design is a process that enables faster, more cost-effective development of dynamic systems, including control systems, signal processing, and communications systems. In Model-Based Design, a system model is at the center of the development process, from requirements development, through design, implementation, and testing. The model is an executable specification that you continually refine throughout the development process. After model development, simulation shows whether the model works correctly.
When software and hardware implementation requirements are included, such as fixed-point and timing behavior, you can automatically generate code for embedded deployment and create test benches for system verification, saving time and avoiding the introduction of manually coded errors. The first step in modeling a dynamic system is to fully define the system. If you are modeling a large system that can be broken into parts, you should model each subcomponent on its own. Then, after building each component, you can integrate them into a complete model of the system. For example, the demo house heat example model of the heating system of a house is broken down into three main parts:

- Heater subsystem
- Thermostat subsystem
- Thermodynamic model subsystem

The most effective way to build a model of this system is to consider each of these Subsystems independently.



Simulation of Three phase electric spring in unbalanced power system by instantaneous power theory

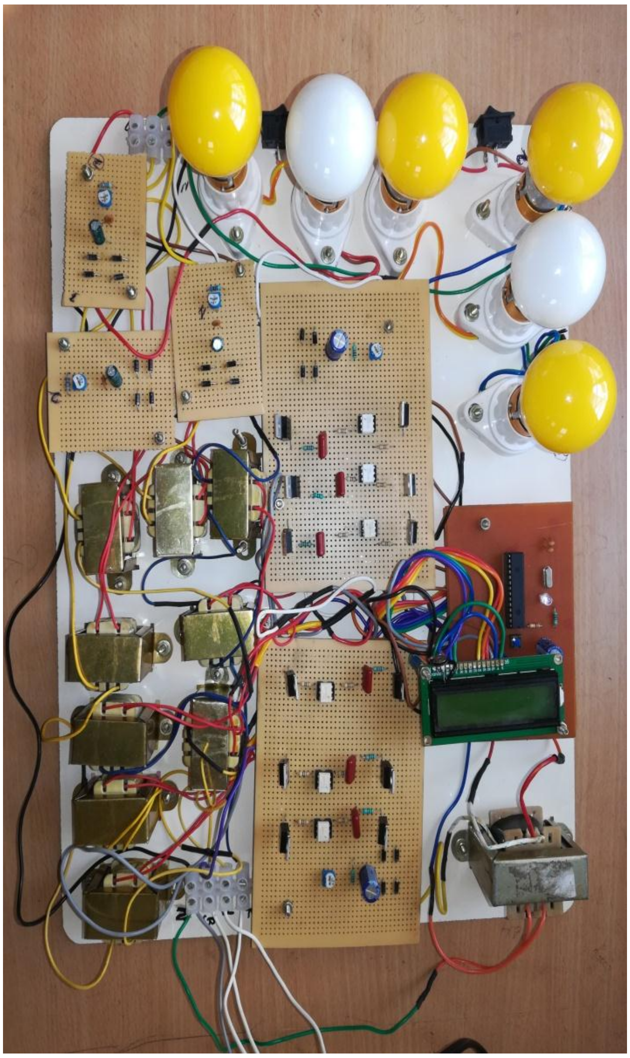


Fig 4.6: Hardware Implementation of 3 phase electric spring in unbalanced system by instantaneous power theory

5. RESULT & DISCUSSION

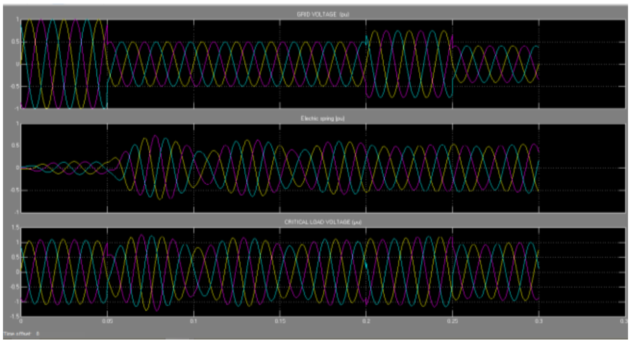


Fig.5.1: Grid Input Voltage during fluctuations

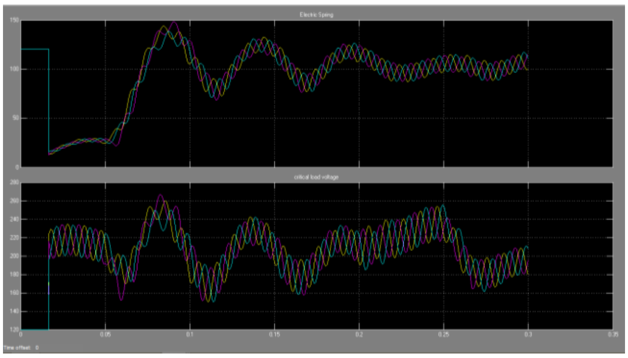


Fig. 5.2: Electric spring output waveform

S.NO	BEFORE ADDING ELECTRIC SPRING	AFTER THE ADDITION OF ELECTRIC SPRING
1.	Voltage and current are not constant.	Voltage and current are constant.
2.	Voltage varying approximately 91V.	It is constant voltage is 415V.
3.	It is more fluctuation.	Reduce the fluctuation.
4.	Low power factor.	Good power factor.

CONCLUSION

Using the Instantaneous Power Theory as the theoretical framework, this paper analyzes the use of 3-ph ES in providing multiple functions of voltage regulation and reduction of power imbalance and oscillating active power. The conditions forminimizing the average and oscillating power have been derived for the first time. Not only does the analysis provides the analytic solution to maintain the power balance in a 3-ph system as previously reported in [18], it can also be used to minimize the oscillating active power. The analysis enables the integration of multifunctional controls in a single controller. The analysis and the proposed control scheme have been practically verified in a hardware setup. The practical measurements show that multiple objectives can be achieved simultaneously.

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