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Voltage Control and Improvement in Load Voltage THD Using Electric Spring in Microgrid

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Abstract: The benefits of Electric Spring (ES) in the hybrid power system alongside with a solar energy source as well as a grid power supply were examined in this research. When an non stabilized event caused by weather conditions happens, the electric spring's capacity to provide quick reactive power adjustment as well as frequency and voltage stability. The converter stability is achieved even in adverse weather conditions because to an efficient ANN control method that has been designed. Simulating the proposed converter in the hybrid system allows for its verification. The findings demonstrate that ES effectively balances the reactive power while stabilizing voltage as well improve power quality

Keywords: *Artificial Neural Network Controller, Electric Spring, Smart Grid, Total Harmonic Distortion, Voltage Regulation.*

1. Introduction

Clean energy sources like wind and solar energy have significantly lowered our energy needs during the last 10 years. It keeps growing as a result of the shortage of non-renewable resources and a growing energy demand with falling operational cost [1, 2]. The expanding number of renewable energy sources connected in distribution networks near load centers makes it hard to determine the electrical grid's immediate generating capacity. These sources could be notified about producing stations or not. Therefore, Dynamic instability and fluctuating mains voltage these type of problems may arise. [3]. The weather has an impact on the quality of electricity generated at remote producing stations that largely employ renewable energy. As the weather changes, the main voltage frequency and stability will also revise. A new control criterion is needed to ensure that the load demands follows power generations rather than power generations follows load demands in order to solve these issues [4].

Numerous techniques for controlling demand sides in order to achieve a stable power generation have been given and investigated in recent study. In [5] explores the utilization of storage devices during times of peak demand. For the clever load regulating, direct control is recommended in [6]. Delay-tolerant real-time pricing and power demand activities are the further demand side management (DSM) strategies [7]. For voltage stability and immediate power balancing, they are inefficient and ineffectual. Due to high feeder resistance and inductance ratios, distribution networks' voltages are dependent on both active and reactive power. Several research scholars have proposed several approaches to the voltage instability problem using distributed resources. Battery energy storage systems (BESS) are said to be capable of handling voltage spikes during PV and wind peak output as well as voltage reductions during heavy loads in [8]. In [9], a brand-new mechanism called the Electric Spring (ES) is presented in analogy to Hooke's law of mechanical systems. Electric spring is more effective at enhancing dynamic stability in hybrid structures with renewable production than batteries and static VAR systems [10]. Electric springs can regulate the way non-critical loads (NCL) use energy and supply critical loads (CL) with greater voltage stability. Electric springs have been proposed in a number of variations, including ES with a capacitor storage as well as ES with storage of batteries [11].

2. Concept Of Es

The force equation of an ideal mechanical spring is taken by Hooke’s law and different spring positions are shown in Figure 1.

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

F is the restoring force of a spring that pursues to coming back to the equilibrium position, x is the distance travelled from the point of equilibrium, and k is the spring constant.

The potential energy (P.E.) of mechanical spring's is given as

$$P.E. = \frac{1}{2} kx^2 \tag{2}$$

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An electric spring can maintain the necessary electric voltage, store electric energy, and attenuate electric oscillations caused by momentary conditions, much like a mechanical spring can.

$$Q = CVa \tag{3}$$

inductive mode and for capacitive mode, are two ways to express an electric spring.

$$Q = - CVa \tag{4}$$

$$q = \int ic.\ dt \tag{5}$$

The capacitor's current *ic*, has an electric charge of *q* and a potential difference of *Va* [12].

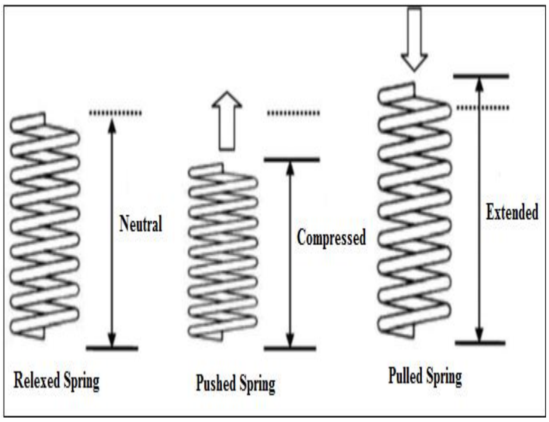

Fig 1: Understanding of different positions of spring

The connection of ES with different loads is shown in Figure 2.

According to the equations, the capacitor's electric charge can inject or absorb voltage that regulates the ES ability to regulate voltage. The capacitor's charge may be adjusted by utilizing a source with variable current. Consequently, an ES may be thought of as a voltage source along with the current controller. An ES can control voltage across a CL by connecting it in combination with a NCL. The ES can perform voltage boosting and reduction operations to preserve a constant or controlled voltage across important loads, much like a mechanical spring that generates mechanical force its neutral point [13-15].

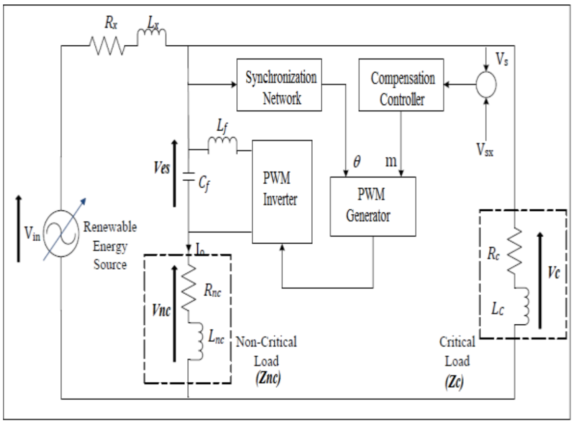

Fig 2: The structure of Electric Spring

Innovative smart load ES technique is a widely used method to increase the stability of hybrid systems with significant renewable energy. It is possible to get a larger working range and more flexible control choices with this electric spring technology. Other advantageous characteristics of this technology include main frequency management, power quality enhancement, and power balancing, in addition to voltage support as well as electric oscillations dampening [16-18].

3. Control Scheme For Es

The voltage varies when a fault in the system is present. The voltage rises or falls based on the type and severity of the malfunction. The low voltage stage is often just connected to the voltage sag.

In the case of voltage sag during a fault, the ANN controller instantly adjusts the training patterns using the weighting function and sends a high output to the PWM circuit, which in turn generates a higher output. Similar to this, when there is a voltage swell, the PWM circuit receives a lower output from the ANN controller and produces a lower output

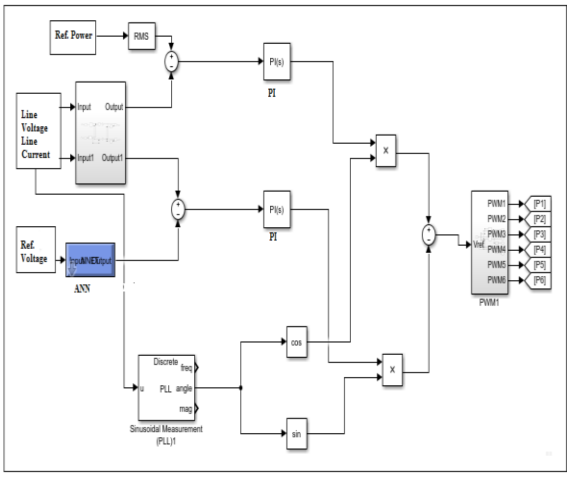

Fig 3: Control Signal using ANN

The ANN controller's control scheme is shown in Figure 3. and it has been utilized to get the phase of the voltage on the grid in order to produce the reference signal for the functioning of ES. The controller ANN is trained offline using pairs of input data(I/P) and output data(O/P) [19].With ANN, it is easier to compute and requires less assumptions to infer the relationship among input and output. By doing this, the assumptions and parameter uncertainties that cause faults in the system are reduced. ES is linked in the series to a NCL in this work. At a different point of common coupling (PCC) voltage as well as available real power changes, ES has to provide consistent voltage for the CL. ANN is created to coordinate the control loops for active and reactive power and to produce a reference signal for the PWM generator. As demonstrated in Figure 4.

By enlarging the neurons, the outcomes are enhanced. The system performs worse if the size is increased over a certain point, though. Ten neurons are selected from the buried layer [20]. Figure 5 depicts a two-layered feed-forward network with a hidden layer that has a sigmoid transfer function and an output layer that has a linear transfer function.

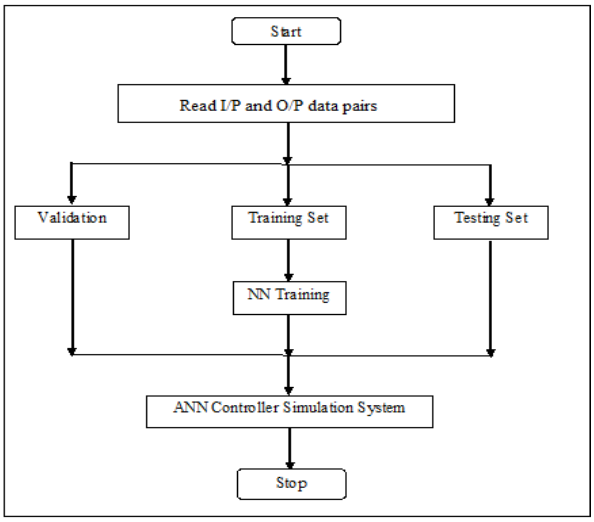

Fig 4: ANN Flowchart

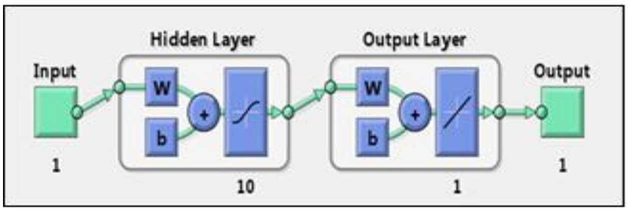

Fig 5: ANN architecture

ANN may be used to analyze the relationship among input and output with a minimal amount of assumptions and processing overhead. Assumptions and uncertainties of system parameters reduces errors. In this work, ES and an NCL are coupled in a series. ES must provide steady real power, as well as voltage to the CL [21]- [26] despite fluctuations in available real power and fluctuating PCC voltage. ANN, which also produces a signal for the PWM generator, coordinates the electrical circuits that are reactive and active. The entire system then undergoes simulation with MATLAB/Simulink and a conventional PI controller is used. CL voltage information and pi gains from the controller are used as data for input and output. They are obtained from the MATLAB environment and stored as datasets. During training of the neural network controller, these data sets are supplied as both input and output matrix to the nn controller toolbox in MATLAB. The Levenberg-Marquardt back propagation technique is utilized to train the controller [27], [28].

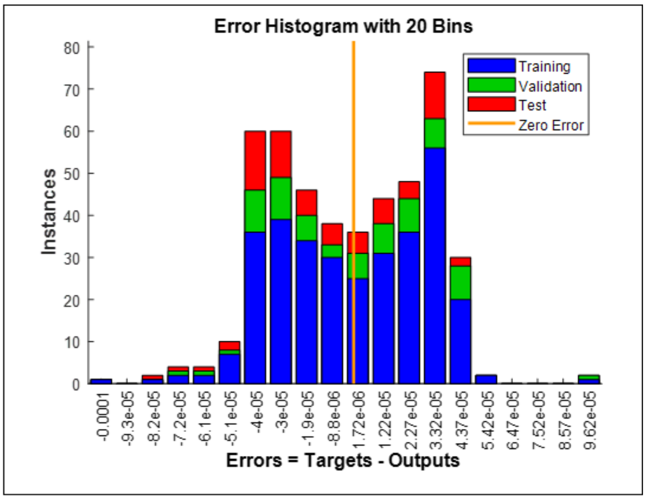

Fig 6: Histogram

The information from the imported data is split into three categories with a percentage of the change for each iteration (Generalization, Validation, and Testing/Training). A 70% training set, 15% validation set, and 15% generalization set are often taken into account. The training phase is over after the controller has been generalized during it. The size of the neurons in the buried hidden layer is determined after the data sets have been partitioned [29].

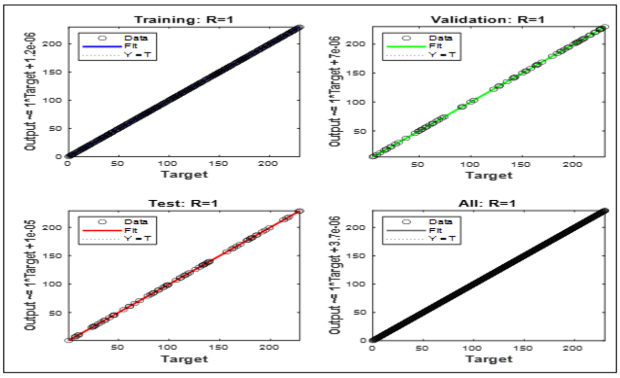

Fig 7: Regression Curve

The Figure 6 displays a histogram of mistakes with 20 bins. Bins are vertical bars that show how many training datasets are contained in each bin. It indicates how many samples in a dataset contain a specific mistake. A regression curve showing the relationship between the controller's output and the targets is shown in Figure 7. If the training is flawless, the network output and targets will match up exactly. However, in actuality, this relationship doesn't happen very often. Each graph shows a dashed-dotted line representing the accurate result and a black solid line representing a linear regression that fits the data correctly. The R Value shows the relationship between output and targets. For R=1, there is a linear connection; for R=0, there is none.

4. Hybrid Power System

A three-phase grid power supply system, one PV producing unit, and a DC/AC converter are all components of a hybrid generating system (HGS) [30–33]. Figure 8 depicts the HGS that regulates voltage and compensates for utility-side reactive power.

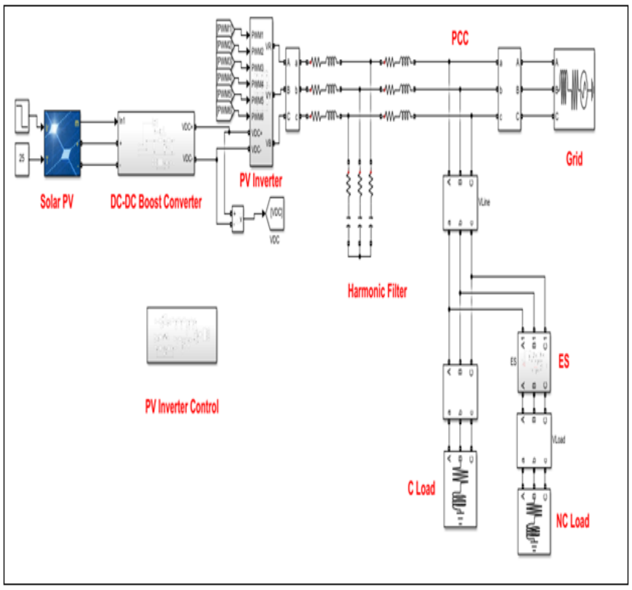

Fig 8: Hybrid power generation model

5. Simulation Results

An LC filter is connected after the inverter to reduce harmonics caused by inverter switching transients. ES is linked to the NCL together with the CL to manage frequency and voltage magnitude as well as to take into consideration reactive power by load. Consideration is given to two examples in both with and without electric springs [34]- [36]. Figures 9 and 10, respectively, display the model responses in capacitive mode spanning CL and NCL. To show off ES's capacity to support voltage, the disturbance source is programmed to generate 217.5 V at t = 0.2 sec. In order to restore the line voltage to its usual reference value, the ES is triggered at t = 0.3 seconds, and the voltage of the ES is increased from almost zero to around 175 V. The voltage from across NCL drops to 50 V when ES is turned on. The voltage is regulated to revert to its initial reference value of 230 V at t = 0.3 seconds. The matching instantaneous values of NCL voltage, electric spring (ES) voltage, and CL voltage show that current is 90^0 times bigger than voltage.

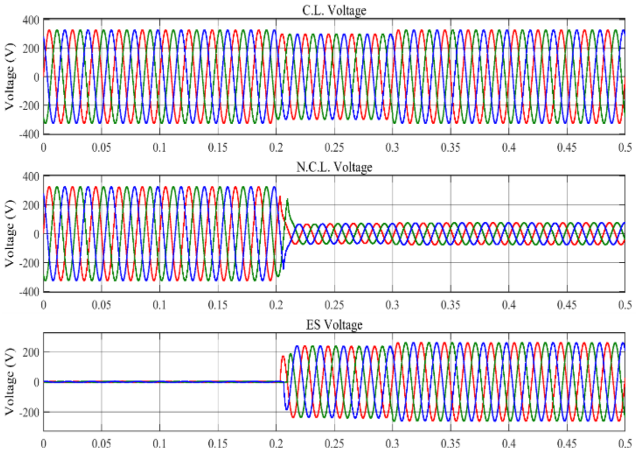

Fig 9: capacitive mode

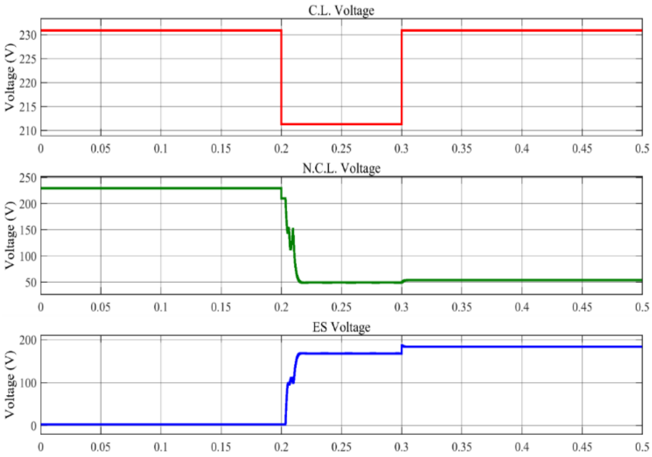

Fig 10: RMS response in capacitive mode

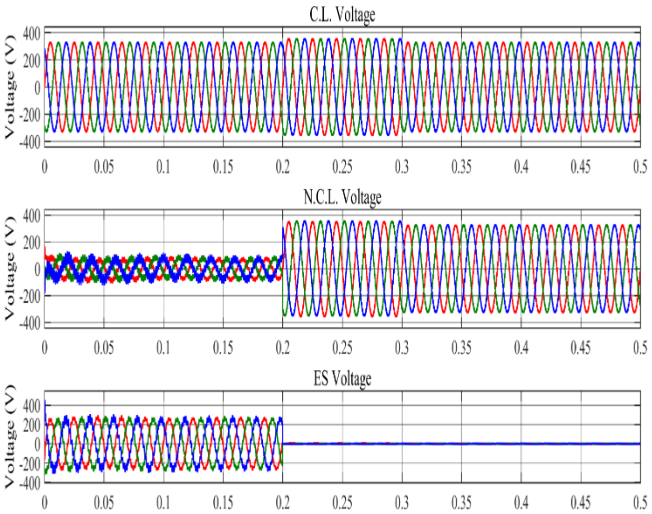

Fig 11: Inductive Mode

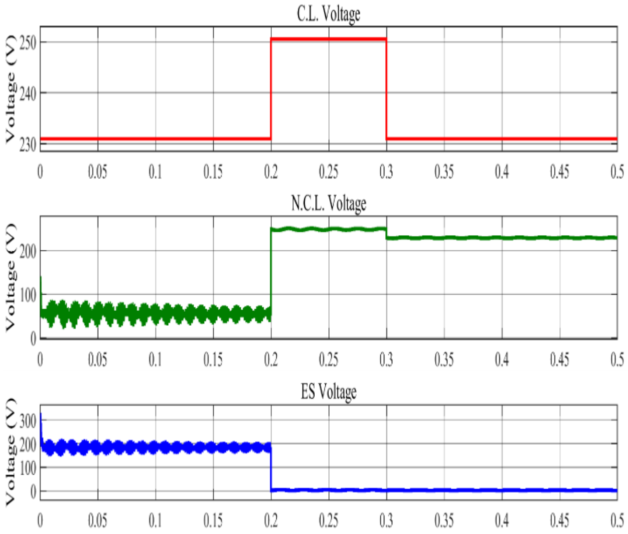

Fig 12: RMS response inductive mode

The Figure 11 and Figure 12 displays the model's inductive mode responses under the CL. A disturbance is induced to produce a voltage of 245 V at time t = 0.2 seconds in order to evaluate the voltage suppression capabilities of ES. The ES is triggered at t = 0.3 seconds to lower the rising line voltage and alter the voltage of the electric spring in order to stabilize the voltage level at 230 V. The voltage across the NCL rises to 245 V when ES is turned on. The matching instantaneous values of the NCL voltage, the electric spring voltage, and the CL voltage demonstrate that the ES is operating well in inductive mode and that the current lags the voltage by 90^0. The load current THD values are shown in Figure 13 and Figure 14 with ES and without ES.

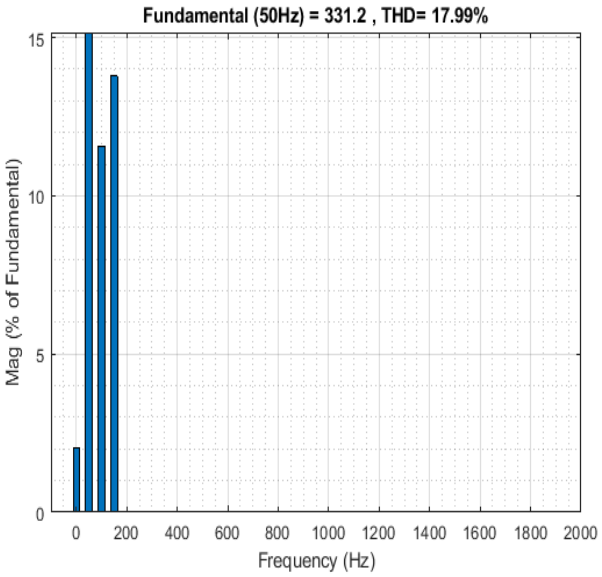

Fig 13: THD in current without ES

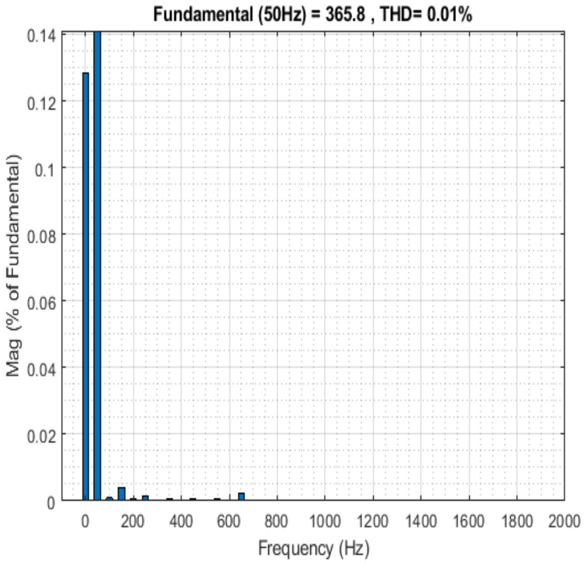

Fig 14: THD in current with ES

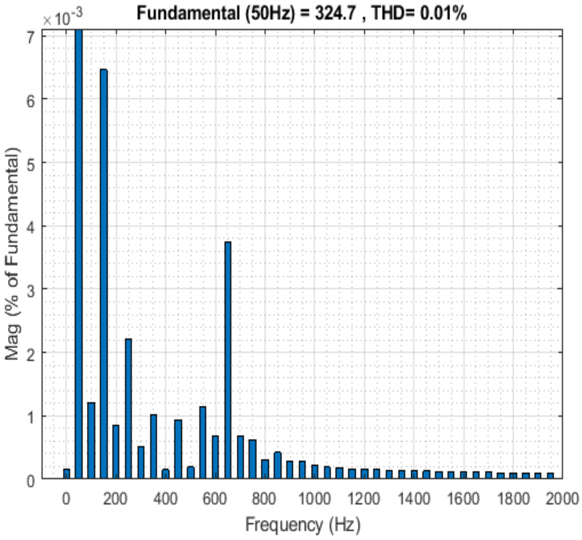

Fig 15: THD in the voltage with ES

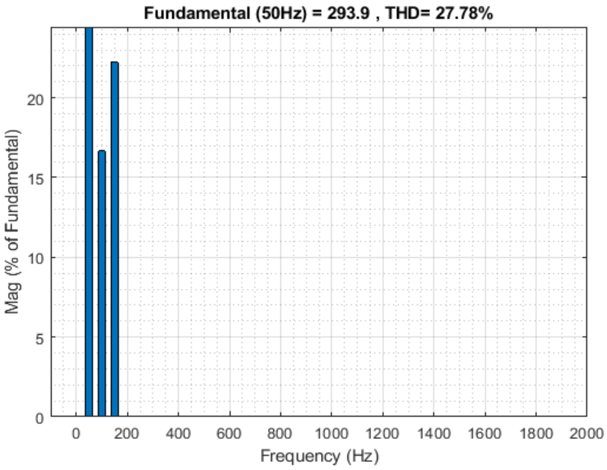

Fig 16: THD in the voltage without ES

The Figure 15 and Figure 16 shows the value of load current THD with considering ES and without considering

ES. The Table 1. shows Simulation results with and without ES.

Table1: Simulation results with and without ES

Parameter	Without ES	With ES
Load Voltage THD	27.78 %	0.01 %
Load Current THD	17.99 %	0.01 %
Voltage Regulation	50 %	2 %

6. Conclusion

This work and earlier studies have demonstrated that the use of ES is a practical solution to the problem of power system instability related to alternate energy source driven grids. In this study, it is demonstrated how an electric spring may use ANN control approach to regulate line voltage, supply power to a CL, and improve the power factor. It has also been shown that a distinct organization can take care of regulation of voltage and power system improvement. The suggested converter may be tested by modelling it in a hybrid structure with MATLAB/Simulink. Under different load conditions, the electric spring's results efficiently stabilize the voltage.

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