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Voltage Regulation Using Artificial Neural Network Controller for Electric Spring in Hybrid Power System

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Abstract: A new smart grid device, the electric spring (ES), was previously used to ensure power and voltage stability in a poorly stand-alone/regulated renewable energy source powered (RES) system. The variable energy generation caused by changes in the environmental condition of RES in the network produces power quality issues and other technical difficulties. A demand-side management strategy has been proposed that involves controlling voltage and power and also installation of the ES using non-critical loads (NCL) and implementation of an artificial neural network (ANN) controller is discussed in this paper. The ANN controller results are compared with conventional controller in the MATLAB Simulink software. This control method would be capable of providing voltage support and power balancing for the critical loads (CL), such as the security system. The improved control system provides novel potential for the ES to be used to a greater extent by ensuring power and voltage stability and enhancing power quality within micro - grid powered by renewable energy.

Keywords: *smart grid, artificial neural network, renewable energy sources, electric spring, power stability***.**

1. Introduction

The growing penetration of distributed PV electricity generating equipment will unavoidably put the conventional distribution grid's current management and planning techniques to the test low voltage distributed networks (LV-DNs). Traditional power systems network infrastructure is only built to accommodate electrical flow in one direction, from the transformer to the residences. The distributed PV system employed in LV-DNs, on the other hand, increases the chance of diverting the flow of power from households toward a substation due to excess PV power generated during bright days. There may be large reverse-power flows as a result of grid voltage and over-voltage changes. These concerns could result in poor operation of protection devices, grid-connected equipment damage, lower system reliability and grid frequency stability, or even power outages. Finally, excessive voltage rise and a mismatch among supply and demand for power are two new difficulties impeding the broad installation of distributed solar systems in power distribution systems[1]. Many approaches have been proposed to address overvoltage or power imbalance issues. These alternatives are classified as (a) traditional tap-changing methods, (b) compensating for reactive power, (c) lowering the quantity of PV power generated, (d) adopting battery-powered energy storage systems (BESS), and (e) demand-side management (DSM). There is prototype change away from traditional generation management and toward demand side management, often known as demand dispatch [2]. Several approaches to demand side management have been proposed in the research paper [3]–[5]. Many of these techniques rely on load shedding and peak load shaving in some fashion, whether through the rescheduling of delay different tolerant loads [6], [7], on-off management from a centralized location [8], the supply of the battery storage [9], or the development of incentives to avoid peak electricity demand. These methods interfere with the freedom and privacy of the end user since they necessitate the use of some form of the information and the communication technology (ICT). The ICT is unreliable during storms and other environmental misfortunes and has issues with signal traversal delay and hacking. Peak load control with battery storage is the best solution, but it is also the most expensive and toxic to implement.

The smart load can be connected to other vital loads like data centres and hospital surgical equipment. The ES structure is simple to execute this design in hotels, massive apartment complexes, and commercial structures. A huge hotel's energy consumption trend has been discussed in [10]. About 68% [11] of the building's total load is made up of heating and lighting, which is a NCL's.

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Despite the fact that the load and supply voltages remain constant, the ES modifies voltage of NCL and its power flow. This is accomplished by introducing voltage into to the grid in conjunction with the current that flows through the NCL [12].

2. Structure of Electric Spring (ES)

The circuitry of three phase ES that is connected to a system is shown in Fig. 1. An inverter is used in the circuitry below to realise the ES. This ES is connected to

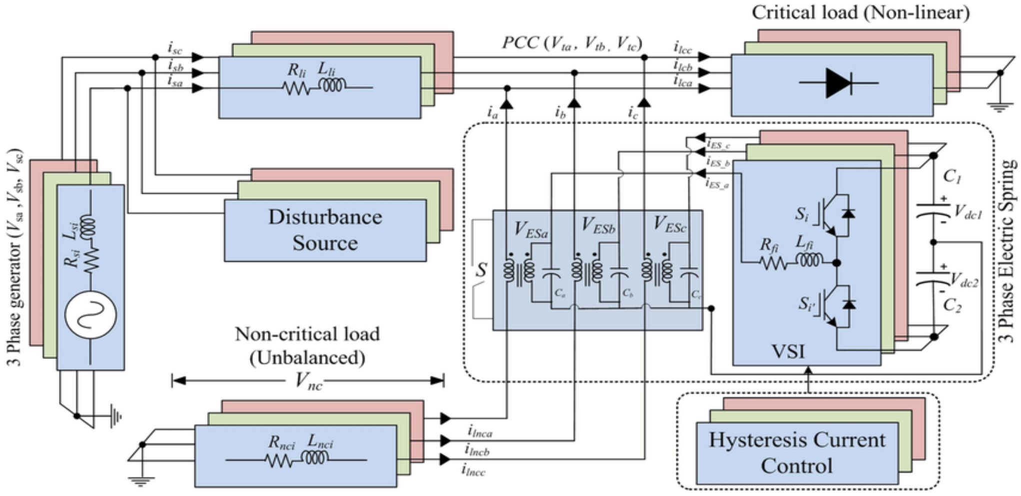

Fig. 1. Schematic of Three Phase Electric Spring

a microgrid fueled by renewable energy sources, as opposed to the normal current-controlled voltage source that drives it. A smart load is a combination of this electric spring with a NCL (such as a refrigerator or air conditioner). The CL and the smart load (for example, a security system) are linked in parallel [13]–[16] .

3. ES Control Scheme

The relationship between input as well as output can be determined using ANN with a small number of assumptions and a low processing overhead. This decreases the inaccuracies generated by the system parameters' assumptions and uncertainties. In this study, ES is connected in a series to a NCL. With varying PCC voltage and available real power changes, ES must maintain stable real power and voltage to the CL[17]–[22] . The reactive and active electrical circuits are coordinated by ANN, which also generates a signal for such PWM generator. The complete system is then simulated using MATLAB/Simulink to use a standard PI controller. As input and output data, critical load voltage data and pi controller gains are used. They are saved in datasets and retrieved from the MATLAB workspace. These data sets are specified as input and output matrices to the nn control toolbox in MATLAB during neural network controller training. For training the controller, the Levenberg-Marquardt back propagation algorithm is used [23], [24].

The imported data information is divided in three groups (Generalization, Validation and Testing/Training), each with a percentage change. Generally, a 70% training set, 15% validation set, and 15% generalisation set are considered. When the controller is generalised during the training phase, the training is terminated. After the sets of data have been partitioned, the size of neurons located in the concealed hidden layer is specified [25].

The results are improved by increasing the size of the neurons. Yet, raising the size beyond a certain point decreases system performance. In the hidden layer, 10 neurons are selected. The Fig. 2 depicts a two-layered feed-forward networks with such a sigmoid transfer function inside the concealed hidden layer as well as a linear transfer function inside the output layer.

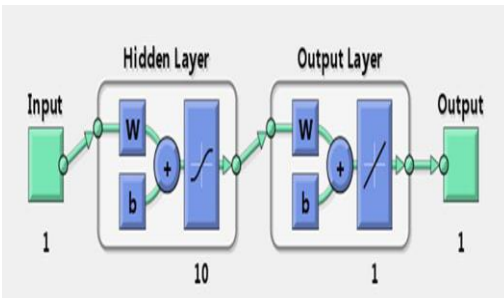

Fig. 2. Architecture of a Network

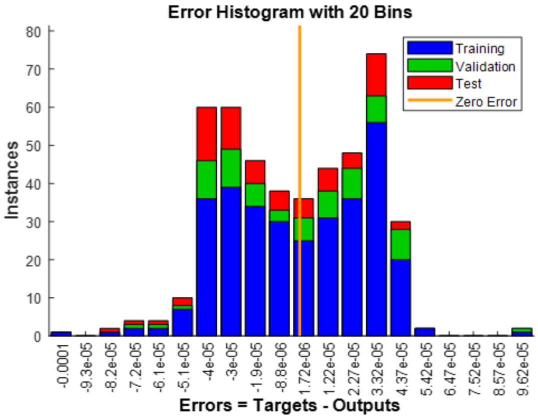

Fig. 3. Histogram error

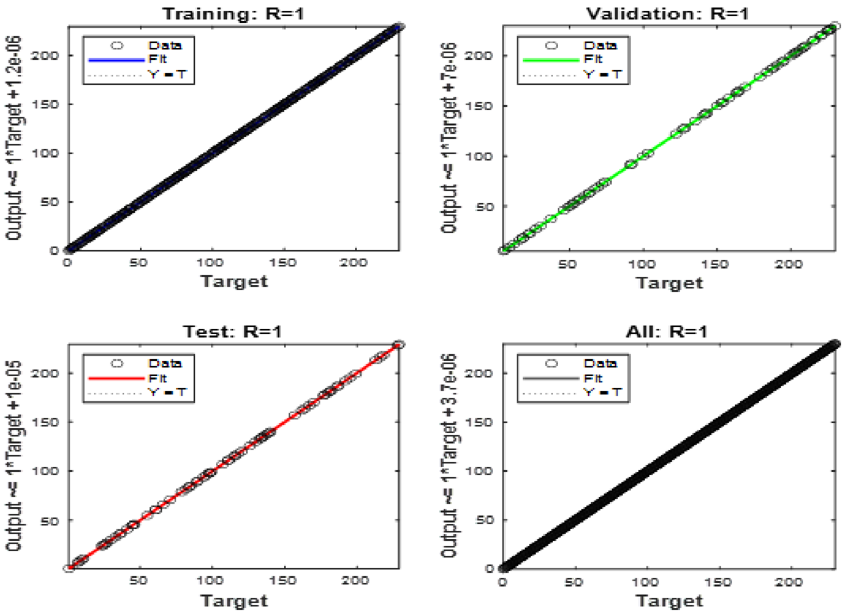

Fig. 4. Regression plot

A histogram of errors with 20 bins is shown in Fig.3. Bins are vertical bars that reflect the amount of training datasets in each bin. It denotes the number of samples in a dataset that have a particular error. Fig.4. exhibits a regression curve illustrating the link between the output of the controller and the targets.

The network outputs and targets will be identical if the training is perfect. In practice, however, this association is infrequent. The dashed-dotted line in each graphic reflects the accurate result, while the dark solid line is the correct fit linear regressions. The R value denotes the connection between the outputs and the targets. There is a linear relationship for R=1 but none for R=0.

4. Simulation Results

The hybrid electric power system with the ES is modelled using MATLAB/SIMULINK, as given in the Fig. 5. The hybrid power system model having solar PV power source and grid power supply source. To reduce harmonics induced by inverter switching transients, a harmonic filter is linked after the inverter. An ES is linked prior to the load on parallel with the CL and in series with NCL to manage frequency, power and voltage magnitude and to account of reactive power by load. In both capacitive and inductive mode critical loads of 100 kW and 150 kvar and noncritical loads of 100 kW and 100 kvar are taken into consideration.

4.1 Capacitive mode (voltage boosting)

The fig. 6 and 7 show the model responses in capacitive mode across CL and NCL respectively. The disturbances source is set to create 217.5 V at t = 0.2 sec to demonstrate ES's voltage support capability.

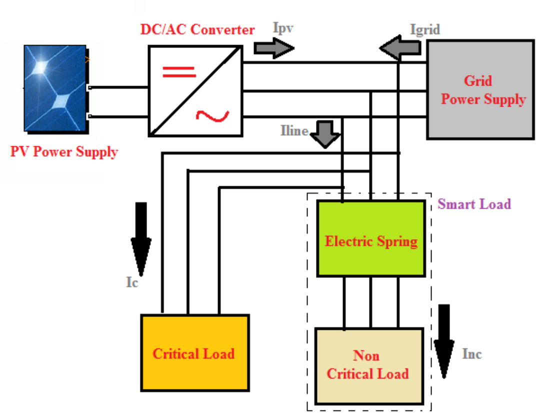

Fig. 5. Hybrid Power System Model

The ES is activated at t = 0.3 sec. to recover the line voltage to its normal reference value, and voltage of ES is raised from near zero to roughly 175 V. When ES is activated, the voltage from across NCL lowers to 50 V, as illustrated in fig. 6. The voltage is regulated back towards its original reference value of 230 V at t = 0.3 sec. The matching instantaneous values of NCL voltage, electric spring (ES) voltage, and CL voltage clearly show that current is 90^0 times greater than voltage. Thus, MATLAB is used to successfully implement an Electric Spring (ES) in the capacitive state as shown in fig. 7.

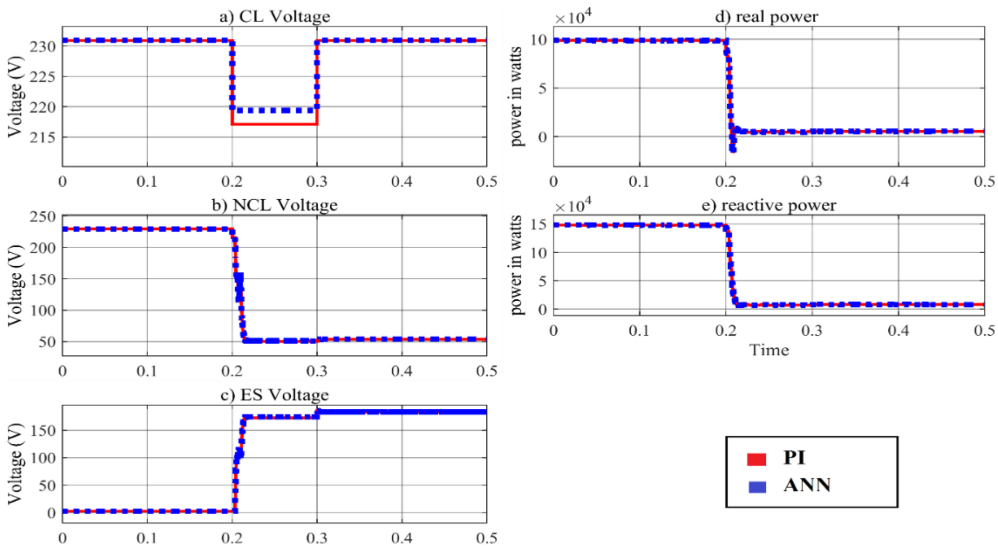

Fig. 6. System responses in capacitive mode (a) observed RMS value of CL (b) NCL voltage (c) ES voltage (d) real power (e) reactive power

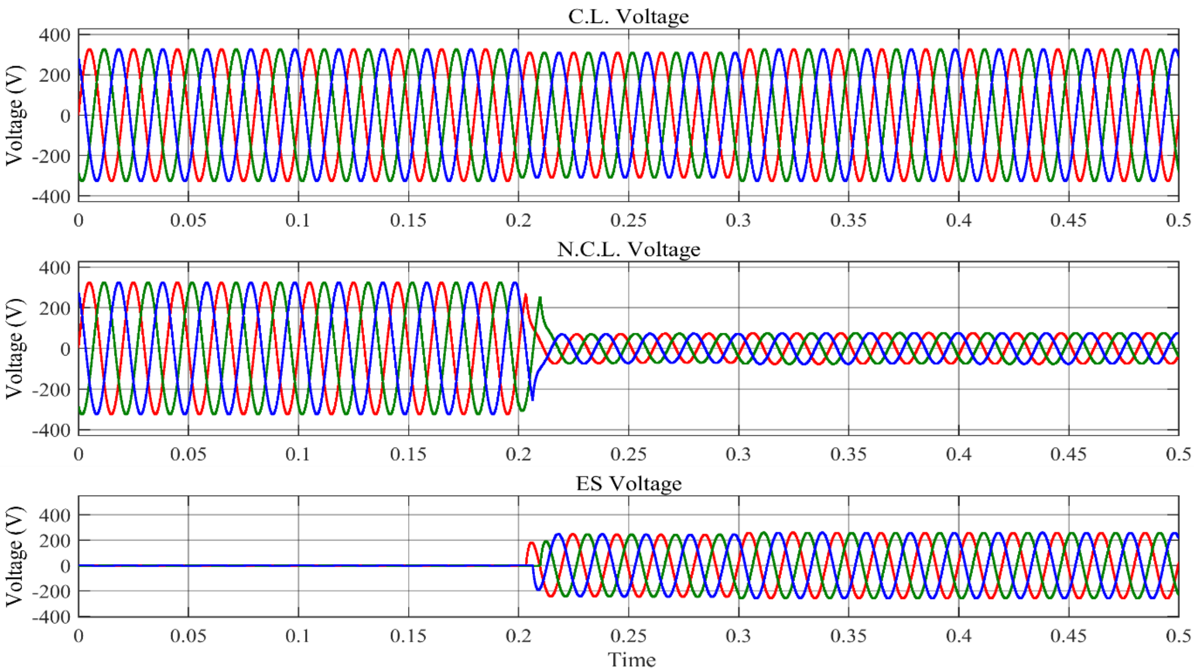

Fig. 7. Observed value of CL, NCL and ES voltage in capacitive mode

4.2 Inductive mode (voltage suppression)

The fig.8 shows the model responses in inductive mode across critical load. To test the ES's voltage suppression performance, a disturbance is created to produce a voltage of 245 V at t = 0.2 sec. The ES is triggered at t = 0.3 sec to suppress the rising line voltage and modify the voltage of the electric spring to stabilise the voltage level 230 V.

When ES is turned on, the voltage across the NCL rises to 245 V, as seen in Fig. 8. The matching instantaneous values of NCL voltage, electric spring voltage, and CL voltage indicate that the current lags voltage by 90^0, indicating that the ES is operating efficiently in inductive mode. As demonstrated in fig. 9, MATLAB is used to successfully implement an ES in inductive mode.

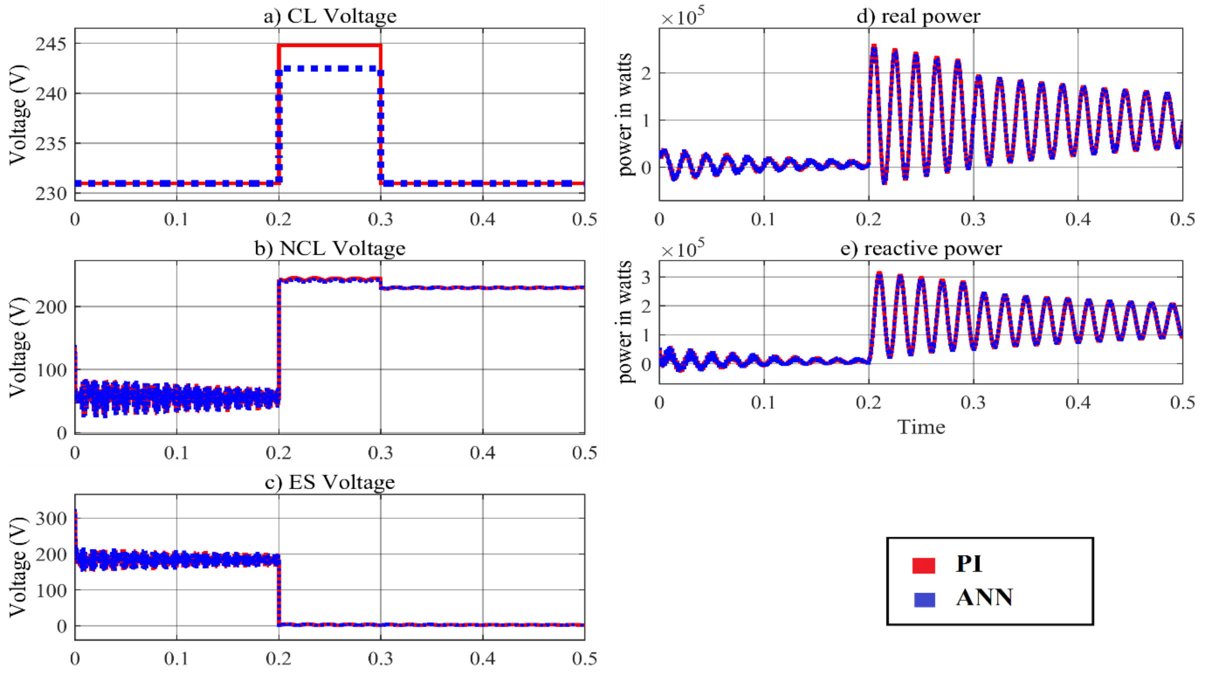

Fig. 8. System responses in inductive mode (a) observed RMS value of CL (b) NCL voltage (c) ES voltage (d) real power (e) reactive power

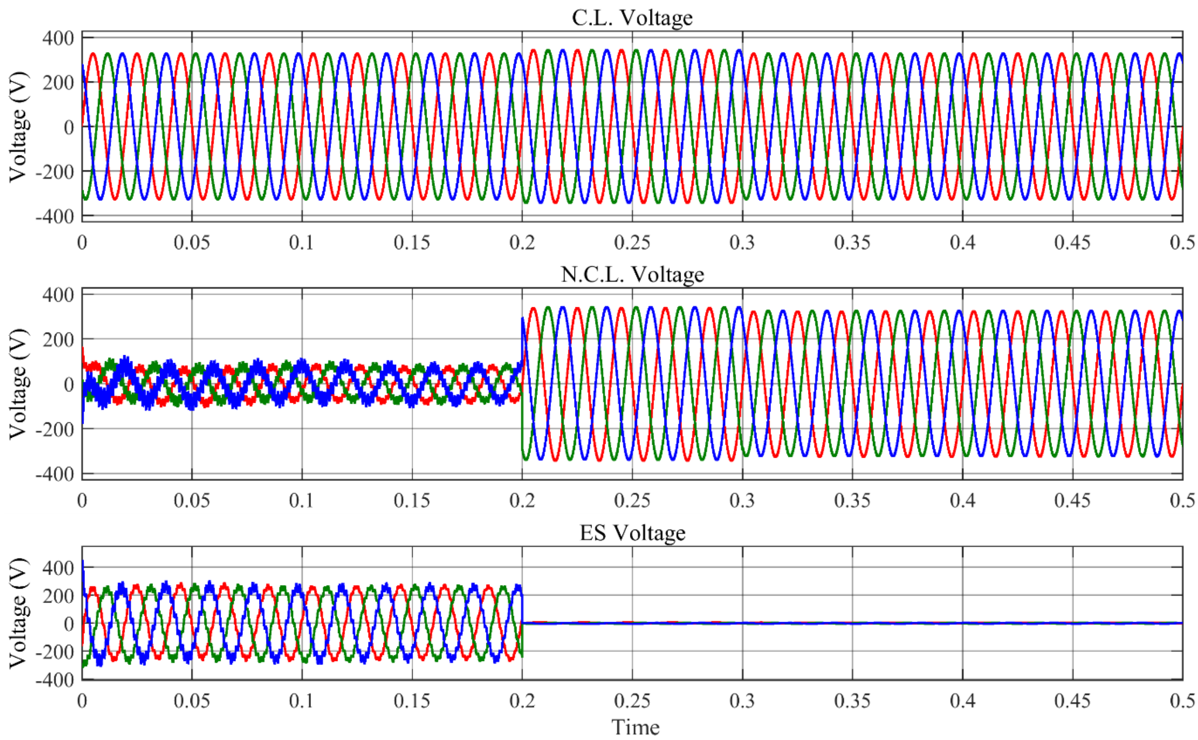

Fig. 9. Observed value of CL, NCL and Electric Spring voltage in inductive mode

5. Conclusion

The obtained results indicate that there are some changes in the voltage magnitudes when an electric spring is attached to non-critical loads. The injected voltage from the ES and the origin voltage are properly synchronised. The electric spring (ES) is a novel solution for voltage regulation and power stability issues in power grids driven by RES. Frequent improvements to the electric spring and its control mechanisms made it possible to maintain the line voltage as a reference voltage, provide continuous power to essential loads, and increase the system's overall power factor. ANN control scheme is used to help increase the stability of the injected voltage, which in turn improves the total voltage stability of the connected devices.

Table 1. Comparison of voltage regulation

Dynamic parameters		**Voltage in volts**		**Time in sec.**	
		PI control	**ANN control**	**PI control**	**ANN control**
Voltage boosting (Sag)	**Critical Load change**	217.5	220	0.2052	0.2048
	Non Critical Load change	50	52	0.2052	0.2048
	ES	170	175	0.2052	0.2048
Voltage Suppression (Swell)	**Critical Load change**	245	242.5	0.2052	0.2048
	Non Critical Load change	245	242	0.2052	0.2048
	ES	0	0	0.2052	0.2048

Conflicts of Interest

"The authors declare no conflict of interest."

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