Artificial Neural Network Analysis of Custom Power Devices for Mitigates the Problem of Power Failures

SAHAYA ELSI. S[1*], MICHAEL RAJ. F[2], PRINCE MARY. S[3], FREEDA. S[4], M. S. EMINA[5]

[1, 5]Department of Electrical and Electronic Engineering, University College of Engineering Nagercoil, (A Anna University Constituent College), Konam, Tamil Nadu, India.

[2]Department of Mechanical Engineering, Stella Mary's College of Engineering, Aruthenganvilai, Azhikal Post - 629202, Tamil Nadu, India.

[3]Department of CSE, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu, India.

[4]Department of EEE, Udaya School of Engineering, Nagercoil, Tamilnadu, India

[*]Corresponding Author: SAHAYA ELSI. S

Abstract

Unified series-shunt compensator (USSC) compensates a variety of power quality problems in the distribution system including voltage sag and voltage swell compensation, flicker reduction, unbalance mitigation, uninterrupted power supply (UPS) mode, power flow control and harmonics elimination. This paper deals with the simulation, analysis and comparison of voltage sag compensation capability of dynamic voltage resistor (DVR), synchronous static compensator (D-STATCOM) and USSC using artificial neural network (ANN). The USSC constructs use of two back to back connected insulated gate bipolar transistor (IGBT) based voltage source inverters (VSIs) with a common dc bus. One of the inverter is connected in series and the other one is placed in shunt with on load. The different operating conditions are applied to test the ability of USSC, D-STATCOM and DVR of the custom power devices. The results showed that artificial neural network calculations have potentially strong for prediction of the better performance of components. However, the proposed ANN showed better performance of the USSC than D-STATCOM and DVR. Hence, the reduced voltage sag and swell in the distribution system mitigates the problem of failures.

Keywords: *USSC, DVR, D-STATCOM, Voltage sags and swells, ANN, Power quality mitigation*

INTRODUCTION

Now a day's voltage fluctuation is a common power quality problem in industrial distribution system. It mainly encompasses voltage sag, voltage swell, voltage harmonics, and voltage unbalance [1-3]. All these notoriously affect the voltage-sensitive equipment and then eventually lead to malfunction. Voltage sag is one of the most severe power quality problems, because of its adverse financial impact on customers. Voltage sags and short interruptions can cause process interruptions with associated costs due to loss of production. Automated factories use sensitive equipment such as power electronics based AC and DC drives, computers, PLCs, etc. These systems need higher quality of electrical power [4-9].

For power-quality improvement, the development of power electronic devices such as flexible AC transmission system (FACTS) and custom power devices have introduced an emerging branch of technology providing the power system with versatile new control capabilities. Since the introduction of FACTS and custom power concept, devices such as unified power-flow controller (UPFC), synchronous static compensator (STATCOM), DVR, solid-state transfer switch, and solid-state fault current limiter are developed for improving the power quality and reliability of the system [10-12]. Advanced control and improved semiconductor for switching of these devices have achieved a new era for power-quality mitigation.

Voltage source converter (VSC) based custom power controllers provides a multifunctional topology, which can be used for voltage regulation and compensation of reactive power, correction of power factor and elimination of current harmonics. For voltage related power quality problems the systems supplying diode bridge converters with high dc link capacitive filters, series active or hybrid filter configurations are preferred [13-18]. However, the loads such as diode/thyristor bridge converters supplying highly inductive loads and/or unbalanced loads, shunt filters are preferred since they can maintain ZVR and compensate for current harmonics and reactive power [19]. A Simplified Control Algorithm for Three-Phase, four-wire unified power quality conditioner are maintained currents and load voltage harmonic levels are maintained below IEEE-519 standards under all conditions [20]. A study on enhancement of loadability of large-scale emerging power systems by using FACTS controllers in large-scale emerging power system networks that achieve significant improvements in operating parameters of the power systems[21-23] such as small signal stability, damping of power system oscillations, security of the power system, less active power loss, voltage profile, quality of the power system, efficiency of power system operations, power transfer capability through the lines, dynamic performances of power systems, and the loadability of the power system network is increased [24]. By using a unified approach of series-shunt compensators it is possible to compensate for a variety of power quality problems in the distribution system [25].

The objective of this paper is to compare the effectiveness of custom power devices such as DVR, D-STATCOM and USSC in power-quality mitigation such as sag compensation, harmonics elimination, unbalance compensation, power-flow control and flicker reduction. The experimental values are analyzed by ANN and the results of the study are presented.

PRINCIPLE AND OPERATION

Unified Series-Shunt Compensator (USSC)

The USSC is a compensation of series and shunt voltage source inverters and its basic configuration is shown in Fig.1. The basic components of the USSC are two 6 pulse voltage source inverters composed of IGBT based - sinusoidal pulse width modulation (PWM) control. USSC includes the function of both series and shunt connected inverters which generates or absorbs reactive power. The series connected inverters injects a voltage Vdq in series with the distribution line, which in turn changes the voltage Vx across the distribution line reactance XL, hence by changing the current and the power flow through the distribution line.

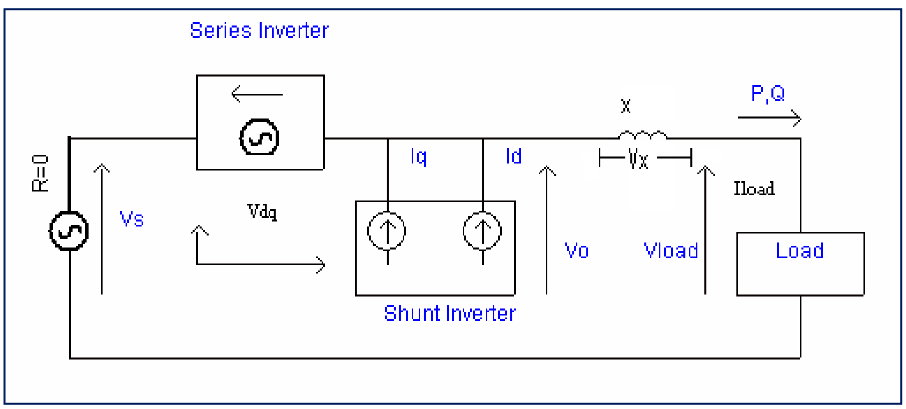

Figure 1. Schematic representation of the USSC.

The USSC is almost similar to the unified power flow controller (UPFC), but the only differences are that the UPFC inverters are in shunt-series connection and it is used in transmission systems whereas the USSC inverters are in series-shunt connection and they are used in distribution systems [25]. The exchange of real power Pinv and the reactive power Qinv can be written in terms of phase angle (angle between the injected voltage Vdq and the line current (I), the injected voltage Vdq and the line current (I), as

 https://doi.org/10.37896/pd91.4/91418

ISSN: 0369-8963

Pinv= VdqIcosɵ (1)

Qinv=VdqIsinɵ (2)

The current injected by the shunt inverters has a real or direct component Id, which can be in phase or in opposite phase with the line and the reactive component Iq, which is in quadrature with the line, thereby emulating an inductive or capacitive reactance at the point of connection with distribution line. The reactive current can be independently controlled which in turn will regulate the line voltage. The USSC behaves as an ideal AC to AC inverter, in which the exchange of real power at the terminal of one inverter to the terminal of the other inverter is through the common dc link capacitor. It should be noted that the shunt inverter is controlled in such a way as to provide precisely the right amount of real power at its dc terminal to meet the real power needs of the series inverter and to regulate the DC voltage of the DC bus. Thus, real power is absorbed from or delivered to the distribution line through the shunt connected inverters, which injects a current at the point of connection.

Dynamic Voltage Resistor (DVR)

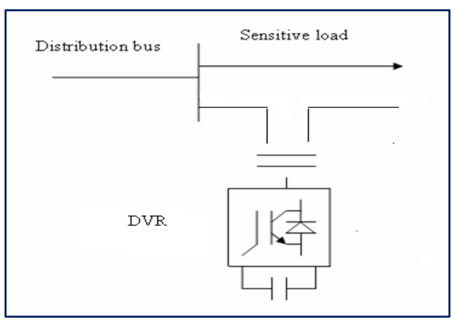

Figure 2. Schematic representation of DVR.

The schematic representation of the DVR as shown in Figure 2. It is used to restore the voltage at the point of connection. The control is based on sinusoidal PWM and requires only the measurement of the root mean square (RMS) voltage at the load point. DVR configuration consists of IGBT based DC-AC power inverter connected through a coupling transformer in series with the AC system and associated control circuits. The VSC generates a three phase AC output voltage, which is controllable in phase and magnitude. These voltages are injected into the AC distribution system in order to maintain the load voltage at the desired voltage reference.

 https://doi.org/10.37896/pd91.4/91418

Synchronous Static Compensator (D-STATCOM)

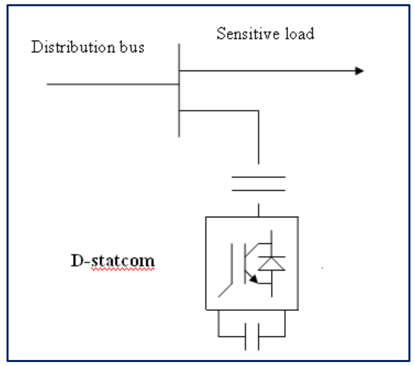

Figure 3. Schematic Representation of the D-STATCOM.

The schematic representation of the D-STATCOM as shown in Figure 3. It is used to regulate voltage at the point of connection. The control is based on sinusoidal PWM and only requires the measurement of the RMS voltage at the load point. D-STATCOM configuration consists of IGBT based DC-AC power inverter connected through a coupling transformer in shunt with the AC system and associated control circuits. The VSC converts the DC voltage across the storage device into AC output voltage. This voltage is in phase and coupled with the AC system through the reactance of the coupling transformer. With suitable adjustment of the phase and magnitude of the inverter output voltage are active and the reactive power exchanges between the D-STATCOM and the AC system.

ARTIFICIAL NEURAL NETWORK APPROACH

ANN has been very popular in many engineering fields because of their interesting features such as learning, generalization, faster computation and ease of implementation. They are signal processing systems that try to imitate the behavior of biological nervous systems by providing a mathematical model of combination and a multiple neurons are connected in a network [26]. However, ANN have found a wide applications in diverse fields like manufacturing, signal processing, bio-electric signal classification, pattern recognition, speech recognition, image processing, communications, autonomous vehicle, navigation control of gantry crane.

In general ANNs are made up of a number of easy and greatly interconnected processing elements structured in layers. A multi-layer perception was developed using STATISTICA

 https://doi.org/10.37896/pd91.4/91418

ISSN: 0369-8963

software. The ANNs is trained to perform a particular task by adjusting the values of the connections (weights) between elements. Typically, neural networks are adjusted (trained), so that a particular input leads to a specific output [27]. This type of training is called supervised training which enables network to predict the value of output after receiving a number of training data from the examined experimental range. Hence, the network is adjusted, based on a comparison between the output and the target, until the network output approximates the target. The network training consists of three main steps:

- The feed forward network training;
- The evaluation of the error between the calculated output values and the target output values.
- The back propagation process of the errors to update connection weights.

The process of training steps when either the mean squared errors reach a pre-defined performance goal or after the completion of a pre-selected number of iterative learning processes, called learning epochs. The back propagation learning rule, also called the generalized delta rule, is commonly applied to feed-forward multilayer networks. The implementation of such algorithm adjusts the network's weights in the steepest descent direction [28].

The back propagation algorithm defined two aspects of the network: first a forward sweep from the input layer to the output layer, and then a backward sweep from output layer to input layer. The forward sweep propagates input vector through the network to provide output at the output layer. The backward sweep is similar to the forward sweep, except that error values are propagated back through the network to determine how the weights are to be changed during the training. During the backward sweep, value passes along the weighted connection in the reverse direction at which it was taken during the forward sweep. The back propagation network of a unit is the hidden layers that send the activation to every unit in the output layer during the forward sweep and so during the backward sweep a unit in the hidden layer will receive an error signals from the every unit in the output layer [29].

An ANN reveals that the training, increased number of neurons in a hidden layer had been used in order to define the output accurately. Statistical methods are used to compare the results produced by the network. Errors occurring at the learning and testing stages are called the mean absolute square (MAE), root-mean square error (RMSE), chi-square error and mean

https://doi.org/10.37896/pd91.4/91418

ISSN: 0369-8963

absolute percentage error (MAPE) values. The measured and predicted output values are very close to each other. The error between experiment and predicted ANN architect 3-23-2 is less than 3 percent. So train network can be used for the prediction of steady state voltage for the given process parameters.

SIMULATION MODEL

Power system consists of three principle components. They are generating system, transmission system and distribution system. This section describes the test system implemented in power system computer aided design (PSCAD) to carry out simulation of the D-STATCOM, DVR and USSC as shown in Figure 4 (a), (b) and (c).

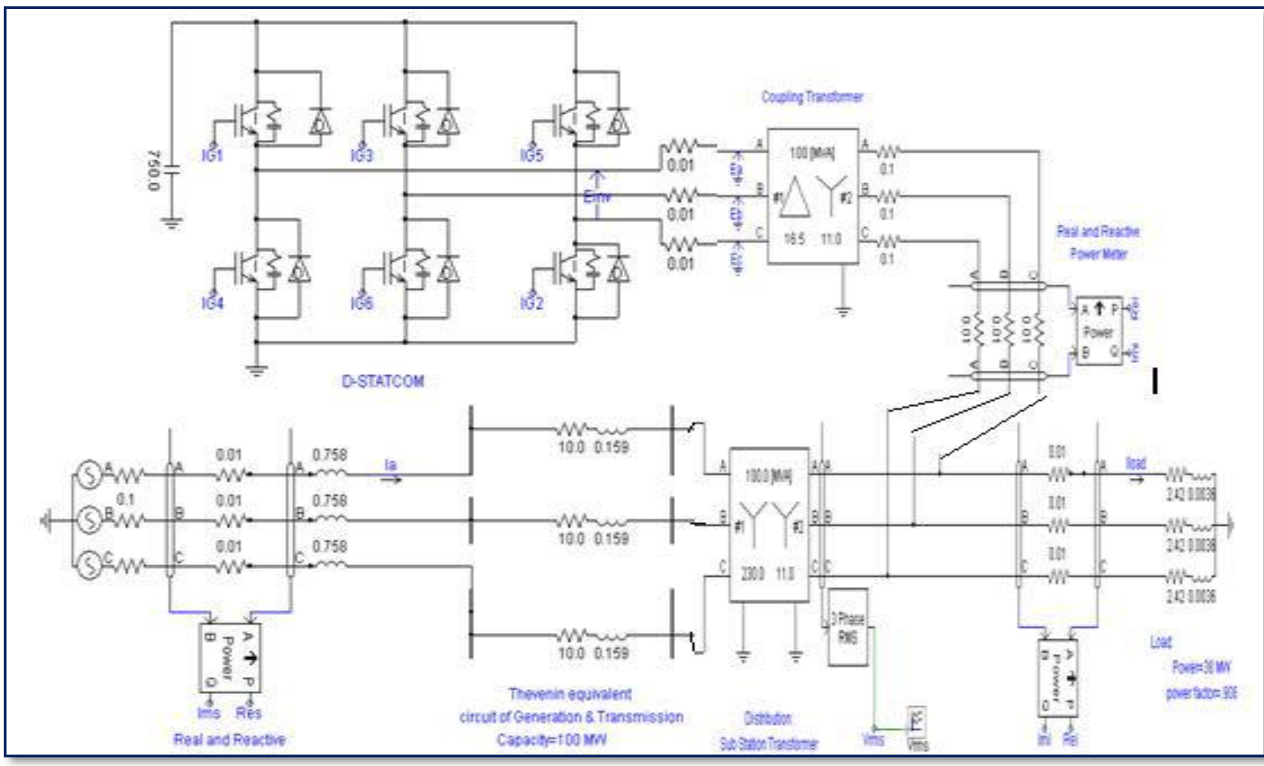

Figure. 4 (a). Simulation Model of D-STATCOM

 https://doi.org/10.37896/pd91.4/91418

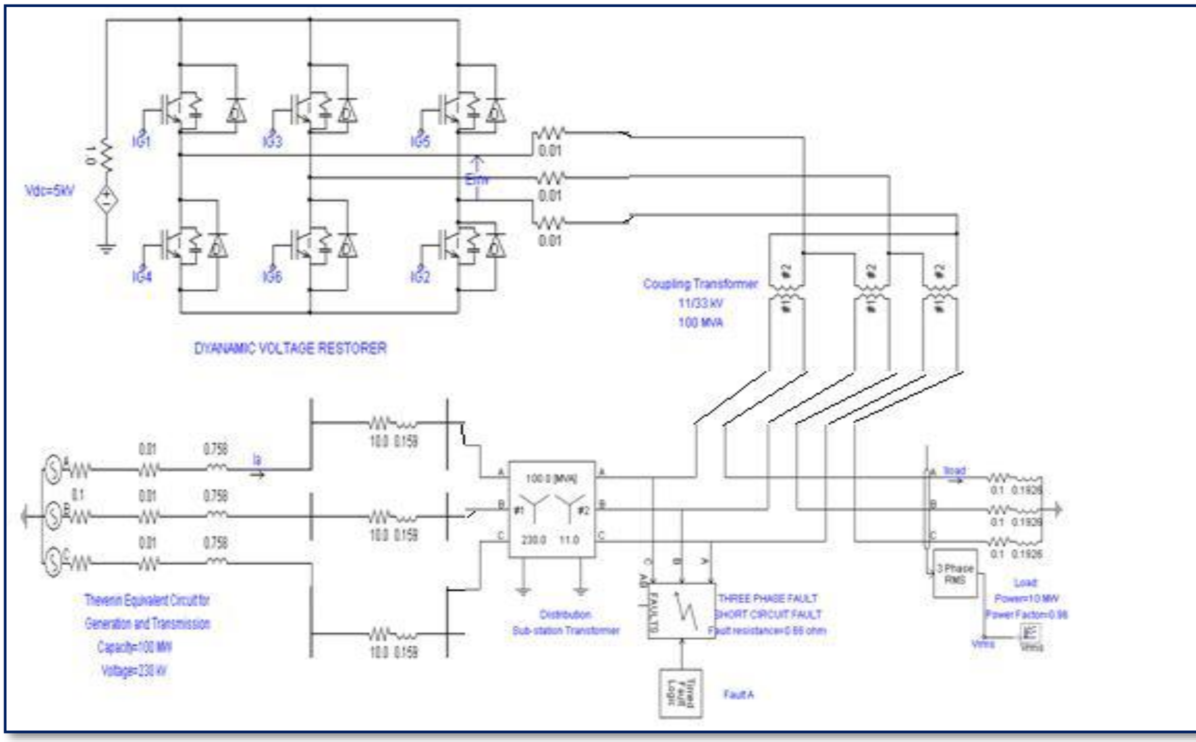

Figure. 4 (b). Simulation model of DVR.

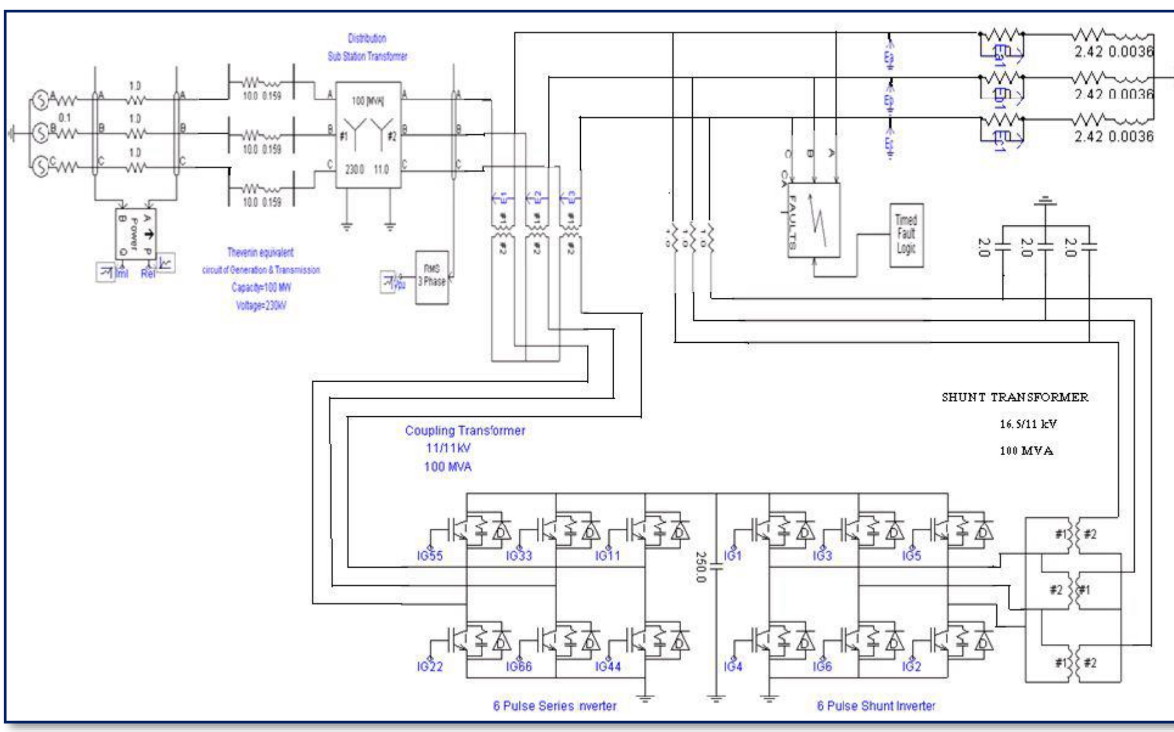

Figure. 4 (c). Simulation Model of USSC.

https://doi.org/10.37896/pd91.4/91418

System parameters for simulation

Source Side (Transmission)

Voltage	= 11KV
Frequency	= 50 Hz
Capacity	= 1MW

Substation Transformer

Capacity	= 1MVA
Voltage rating	= 11/11 KV
Leakage reactance	= 0.02p.u
Winding type	= Y/Y

Load 1	Power	= 15 KW
Load 2	Power	= 10 KW

Voltage Source Converter

Capacitor size	= 750μF
Coupling transformer capacity	= 1 MVA
Voltage rating	= 11/11 KV
Frequency	= 50 Hz

The VSC converts the DC voltage across the storage device into a set of three phase ac output voltages. These voltages are in phase and coupled with the ac system through the coupling transformer. The VSC connected in shunt with the ac system provides a better voltage regulation and compensation of reactive power.

SIMULATION RESULTS

The performance of the USSC model is evaluated by means of simulations using the PSCAD/EMTDC transient simulation program. The USSC is placed in a 22-kV distribution system with a static load of 5.2 MVA. There are twelve single-phase transformers with each rated at 1 MVA, 22/4.16 kV and a leakage reactance of 0.01 p.u., connecting the USSC to the distribution system. Simulations were carried out to illustrate the effectiveness of the USSC as a unified compensator for voltage regulation; voltage sag compensation, voltage flicker reduction, and voltage unbalance mitigation.

Capabilities of USSC versus D-STATCOM and DVR

USSC for Voltage Sag Compensation

To illustrate the use of the USSC in compensating voltage sags, a voltage sag condition is simulated by creating a balanced three-phase fault using a three-phase generator. For the system without the USSC, the load voltage drops from 1.0 to 0.50 p.u. This is a voltage sag condition which is due to a three-phase fault created at time t = 1.5s for a duration of 0.75 s. For the system with the USSC connected, the load voltage increases from 0.50 to 1.0 p.u. The load voltage return to its rated voltage due to the voltage sag compensation capability of the USSC. Comparing the voltage sag compensation capability of the USSC, D-STATCOM and DVR, the results are shown in Table 1 in terms of the minimum, maximum and steady-state voltage values.

Table 1. The Voltage Sag Compensation Capability of DVR, D-STATCOM and USSC.

Device	Minimum voltage	Maximum voltage	Steady-state voltage
DVR	0.97	0.97	0.97
D-STATCOM	0.87	1.14	0.98
USSC	0.93	1.09	1.00

USSC for Voltage Flicker Reduction

Voltage flicker which is a phenomenon of annoying light intensity fluctuation caused by variable electric loads and arc furnaces have been a major power-quality concern. To illustrate the use of the USSC in reducing voltage flicker, simulations were carried out by first connecting a variable electric load of 5.2 MVA, 22 kV as the source of voltage flicker. The flicker effect of a phase RMS voltage for the system without the USSC connected. By connecting the USSC, it can be seen that the RMS voltage of phase A is flicker free.

 https://doi.org/10.37896/pd91.4/91418

USSC for Voltage Unbalance Mitigation

In this simulation, initially an unbalanced voltage condition is created by applying two single phase to ground faults on the phase A and phase Cat time t = 0.5s for a fault duration of 100 ms. The simulation results of the three-phase unbalanced voltages for the system without the USSC connected. It can be seen that during the fault condition, the maximum phase voltages are Va = 14.5 kv, Vb = 19.21kv, and Vc = 10.5kv. The percentage of voltage unbalance is calculated and found to be 28.7%. With the application of USSC, the three-phase load voltages are recorded. The presence of the USSC, the load voltage profile has improved in which the phase A and C voltages are increased and the phase B voltage is reduced, thus making the three phase voltages more balanced. The percentage of voltage unbalance decreases from 28.7% to 1.6%. For the cases with D-STATCOM and DVR connected the simulation results show that the percentage of voltage unbalance are reduced to 5.03% and 2.2%respectively.

USSC Acting in UPS Mode

To show that the USSC can operate in uninterruptible power supply (UPS) mode, an outage is first created at time t = 1.5s for a duration of 0.75 s using a three-phase fault generator. When the USSC is connected in the system, the USSC recovers the load voltage from 0.0 to 1.00 p.u. within a short time.

USSC for Power-Flow Control

The flow of instantaneous active and reactive powers into or out of the USSC are investigated using the transient simulation. When a fault occurs at time t = 1.5s for a duration 0.75 s, the active and reactive powers into the system. The simulation result indicates that during the fault period, both the active and reactive powers of the system increase. The exchange of real power can be made in either direction between the series and shunt inverters of the USSC. With the USSC connected in the system, the reactive power of the system is reduced from 1.2 MVAr to zero in order to achieve a steady-state value of active power. Thus, the active and reactive power flows are controlled and maintain a pre-fault levels.

Harmonic Elimination

Simulation results that the USSC inverters generate a voltage total harmonic distortion (THD) of 78%. Due to high frequency switching losses, the inverters have generated a THD

https://doi.org/10.37896/pd91.4/91418

ISSN: 0369-8963

which is higher than the acceptable level of 5%. Therefore, filtering is indispensable so as to eliminate the harmonics generated by the USSC. Several methods can be used for reducing the harmonics produced by the USSC. To the effect of using an inductance–capacitance (LC) passive filter, simulations were carried out and the THD of the system without and with the filter inserted into the system are recorded.

ANN Modeling

In this study, STATISTICA platform is used to train and test the ANN. In the training, increased number of neurons (5–10) in a hidden layer had been used in order to define the output accurately. First layer of ANN is corresponding to input parameters like minimum voltage, maximum voltage and average voltage. Outer layer of the ANN is for the DVR, D STATCOM and USSC systems. After training the network successfully, it has been tested by using the known test data. The training parameters used in this investigation are listed in Table 2. After successful training, it was used to predict the performance of DVR, D STATCOM and USSC systems within the trained range. Statistical methods are used to compare the results produced by the network.

 https://doi.org/10.37896/pd91.4/91418

ISSN: 0369-8963

Table 2. Statistical values for predictions of DVR, D STATCOM and USSC using various algorithms and topologies.

Training algorithm	Architecture	Transfer function output	Transfer function hidden	MAE		RMAE		Chi square		MAPE	
				Training	Testing	Training	Testing	Training	Testing	Training	Testing
MLP	3-23-2	Identity	Tanh	0.0032	0.0032	0.0057	0	0.0029	0	0.0316	0.0007
MLP	3-23-2	Identity	Tanh	3.5311	3.6805	0.067	0.0592	3.5273	3.6806	0.1486	0.1164
MLP	3-23-2	Identity	Tanh	3.8522	3.7541	0.071	0.0624	3.6213	3.7856	0.1685	0.1056
RBF	3-23-2	Identity	Gaussian	0.5022	0.7594	0.4764	0.0628	0.0186	0.0002	2.8541	0.1595
RBF	3-23-2	Identity	Gaussian	0.0627	0.0072	0.0706	0.0159	0.0016	0.0001	1.9289	0.1968
RBF	3-23-2	Identity	Gaussian	0.0721	0.0082	0.0866	0.0215	0.0018	0.0001	1.9591	0.1998

https://doi.org/10.37896/pd91.4/91418

Prediction of ANN modeling

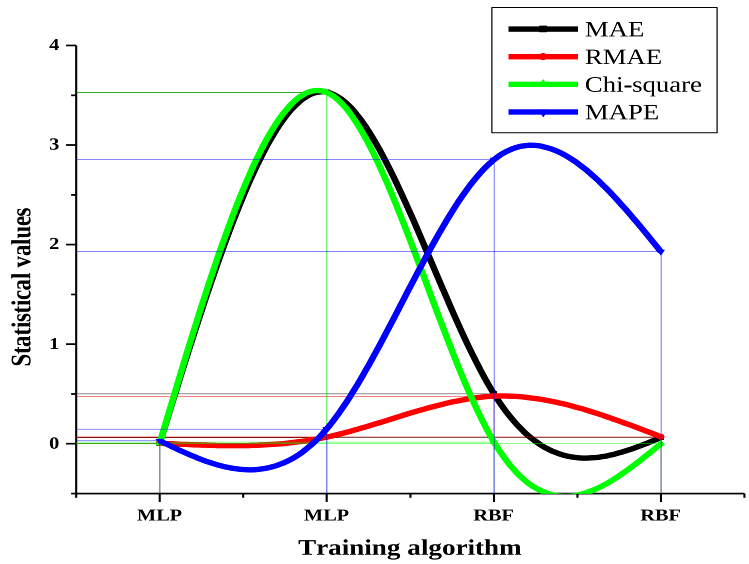

Figure 5. Performance Comparison of MLP and RBF Prediction Models for Training Algorithm.

Table 3: The Predicted Values of MLP and RBF Models.

Properties	Parameters	Design data values	
		MLP	RBF
USSC	Test	0.99999	0.994286
	Train	0.99998	0.999563
DVR	Test	0.99995	0.994266
	Train	0.99992	0.999669
D STATCOM	Test	0.99994	0.993904
	Train	0.99991	0.999721

The performance of the networks for RMAE, MAE, Chi-square and MAPE vs. the statistical values for the two training algorithms is shown in Figure 5. The performance of the networks indicates that the MLP neural network architecture with (3-23-2) topology was chosen as the best topology for the estimation of MLP and RBF. This has a RMAE of 0.9995 and 0.9993 for both training and testing data sets. Regarding RMSE and MAE for the best chosen

 https://doi.org/10.37896/pd91.4/91418

ISSN: 0369-8963
architecture MLP, RMSE was 0.1782 for training data-set and 0.1848 for testing data-set, whereas MAE was 0.1513 for training data-set and 0.1616 testing data-set. The results indicate that the difference between RMSE and MAE are insignificant indicating the variance in the individual errors of the testing set is almost of the same magnitude. The results for training and testing data for the network algorithms with different topologies, MLP and RBF, are summarized and presented in Table 3.

Comparison of RBF and MLP predicted values

The estimation capabilities of the MLP and RBF modeling techniques are examined and compared as shown in Figure 6 and Figure 7. Though both models based on MLP and RBF performed well and offered stable responses in predicting the combined interactions of the independent variables with respect to the response, yet the MLP-based approach was better in fitting to the measured response in comparison with the RBF model as shown in Figure 8 and Figure 9.

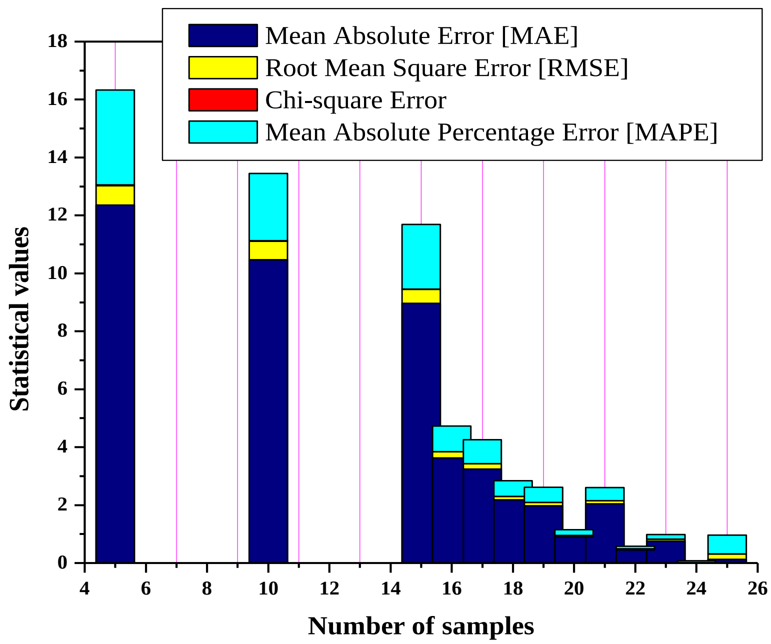

Figure 6. Number of samples for USSC (DVR) versus statistical values for testing.

 https://doi.org/10.37896/pd91.4/91418

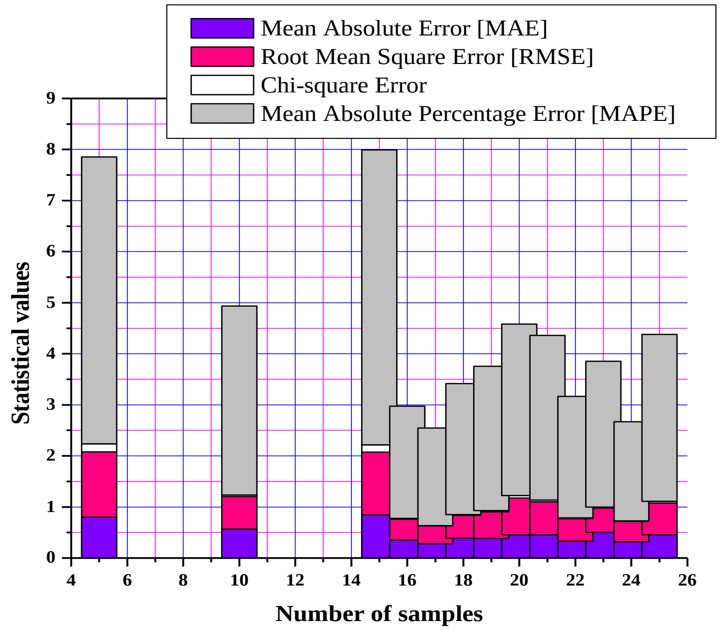

Figure 7. Number of samples for USSC (DVR) versus statistical train values.

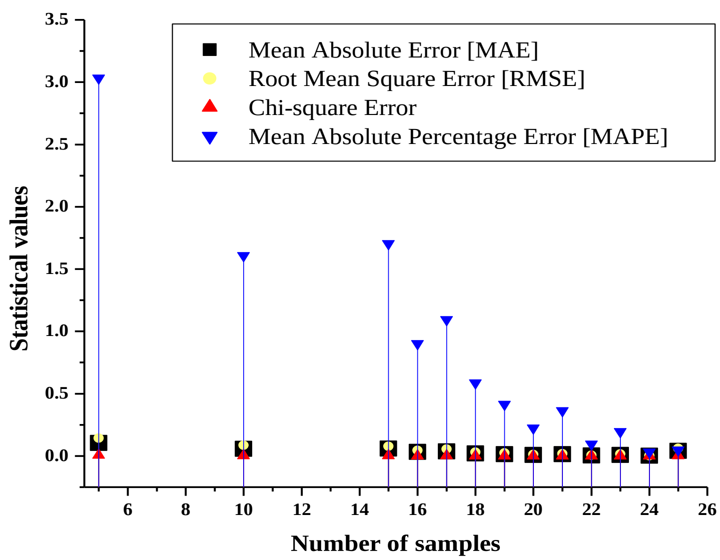

Figure 8. Number of samples for USSC (D STATCOM and USSC) versus statistical test values.

https://doi.org/10.37896/pd91.4/91418

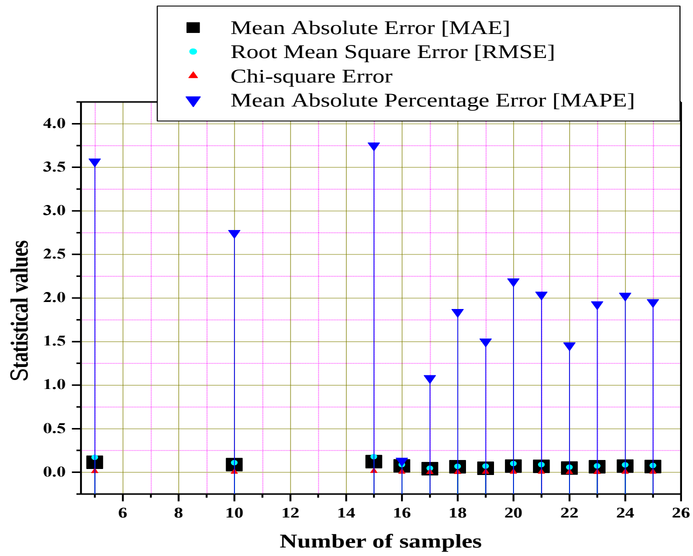

Figure 9. Number of samples for USSC (D STATCOM and USSC) versus statistical train values.

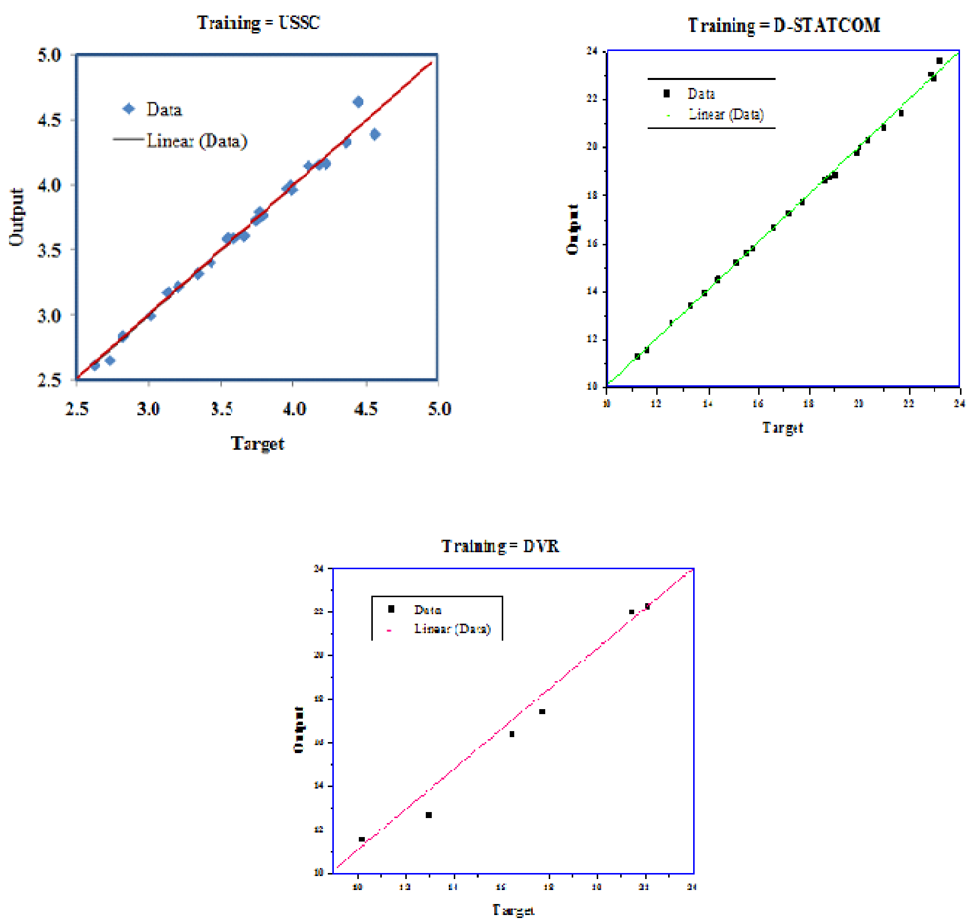

Figure 10. Experimental and predicted values of USSC

 https://doi.org/10.37896/pd91.4/91418

ISSN: 0369-8963

This study compares the performance of RBF and MLP methodologies with their modeling, prediction of various DVR, D-STATCOM and USSC. The conditions to get optimal response with 0.99999 of MLP and 0.994286 of RBF were found to DVR of the system. Furthermore the response of 0.99995 of MLP and 0.994266 of RBF were found the D-STACOM and USSC of the system. The predicted values by MLP as well as the RBF models are tabulated in Table 3 and the experimental and predicted values of USSC as shown in Figure 10. Comparison between MLP and RBF by ANN and RSM models, the correlation coefficients for ANN and RSM are 0.9762 and 0.999, respectively, which are very close to unity. Depending on the nonlinearity of the problem and the number of parameters, an ANN model may require a high computational cost to create when compared with a response surface model.

CONCLUSION

In this study, the major contributions, important observations and conclusions of the power quality problem in the primary distribution system was studied. The operation of USSC as reactive power source and load was examined. Also, it has been observed that the harmonic content of inverter output voltage when USSC operates as reactive power load is different from that of the inverter voltage when the USSC operates as reactive power source. The size of the dc capacitor also plays a major role in the percentage voltage regulation. A comparison is made between the USSC and the other custom power devices such as D-STATCOM and DVR in terms of their capabilities in power-quality mitigation. The USSC gives a better performance in power-quality mitigation, especially in voltage sag compensation and power-flow control, and also provide more power-quality solutions as compared to the D-STATCOM and DVR. From the results obtained, ANN technique can be effectively used to determine optimum reaction parameters in this system and more suitable due to its capability for better predictions modeling technique.

REFERENCES

[1] Lutfu Saribulut, Mehmet Tumay and Đlyas Eker. Performance analysis of fuzzy logic based unified power flow controller. *World Academy of Science, Engineering and Technology* 2008; 45; 320-328.

[2] Monaaf DA, Al-Falahia, Kutaiba S, Nimma, Shantha DG, Jayasinghe, Hossein Enshaei and Josep M Guerrero. *Power management optimization of hybrid power systems in electric ferries. Energy Conversion and Management* 2018; 172; 50-66.

 https://doi.org/10.37896/pd91.4/91418

[3] Bhim Singh, Sunil Kumar Dube and Sabha Raj Arya. A improved control algorithm of DSTATCOM for power quality improvement. *Electrical Power and Energy Systems* 2015; 64; 493–504.

[4] B Singh, V Verma, A Chandra and K Al-Haddad. Hybrid filters for power quality improvement. *IEE Proc Generation, Transmission and Distribution* 2005; 152; 365–378.

[5] D del Puerto-Flores, R Ortega, JMA Scherpen, Chi-Seng Lam and Yongheng A. Cyclodissipativity characterization of power factor compensation of nonlinear loads under nonsinusoidal conditions. *Int J Circ Theor* 2012; 40; 1053–1069.

[6] Yang, Qing Zhong, Yandong Chen and Keng-Weng Lao. Advanced Power Electronic Converters and Power Quality Conditioning. *Hindawi Journal of Electrical and Computer Engineering* 2018; 1-2.

[7] Isaac Cohen, David Wetz, Stepfanie Veiga, Qing Dong and John Heinzel. Fuzzy Logic Control of a hybrid energy storage module for naval pulsed power applications. *International journal of fuzzy logic systems* 2016; 6; 5-11.

[8] Pudi Sekhar, K Venkateswararao and T Devaraju. Power quality enhancement using custom power devices. *International Electrical Engineering Journal* 2012; 3; 745-750.

[9] P Satish Kumar and M Venkatesh. Custom power devices for improve power quality. *International refereed journal of engineering and science* 2015; 11; 34–39.

[10] Qianyi Liu, Yong Li, Sijia Hu and Longfu Luo. A Controllable inductive power filtering system: modeling, analysis and control design. *Electrical Power and Energy Systems* 2019; 105; 717–728.

[11] G Srinivas, T Santosh and Chaitanya. Power Quality Improvement Using Facts Device (STATCOM). *International journal of current engineering and scientific research* 2015; 4; 75–80.

[12] Narasimha Pandit and RL Chakrasali. Power quality issues in Indian power distribution utilities and feasible solutions. *International journal of scientific & technology research* 2017; 6; 23–26.

ISSN: 0369-8963

[13] L Moran, I Pastorini, J Dixon and R Wallace. Series active power filter compensates current harmonics and voltage unbalance simultaneously. *Proc IEE Gener Trans and Distrib* 2000; 1; 31–36,

[14] Amit Kumar Jindal, Arindam Ghosh and Avinash Joshi. The protection of sensitive loads from interharmonic currents using shunt/series active filters. *J Electric Power Syst Res* 2005; 73; 187-196,

[15] S Suganya1 and Suresh PV. System Improving the Power Quality in a Grid Integrated IOSR. *Journal of Electrical and Electronics Engineering* 2016; 11; 1; 76-80.

[16] Aparna BR, GC Shivasharanappa and Anguraja RR Prakash. Unified Power Quality Conditioner (UPQC) in Alleviation of Power Quality Issues. *International Journal of Scientific and Research Publications* 2016; 6; 8; 269-274.

[17] Gowtham N and Shobha Shankarb.UPQC: A Custom Power Device for Power Quality Improvement.*Materials Today: Proceedings* 2018; 5; 965–972.

[18] RSheba Rani, CSrinivasa Rao and M Vijaya Kumar. PSPWM based Five-Level Shunt Active Filter for Power Quality Improvement in Power System Network. *Energy Procedia* 2017; 117; 794-801.

[19] Bhim Singhy and Venkateswarlu P.A Simplified Control Algorithm for Three-Phase, Four-Wire Unified Power Quality Conditioner. *Journal of Power Electronics* 2010; 10; 1; 91-96.

[20] Bindeshwar Singh, NK Sharma and N Tiwari.A Study on Enhancement of Loadability of Large-Scale Emerging Power Systems by Using FACTS Controllers. International *Journal on Computer Science and Engineering* 2010; 02; 05; 1893–1903.

[21] Muhammad Adnan, Muhammad Tariq, Zhenyu Zhou and H Vincent. Poor Load flow balancing and transient stability analysis in renewable integrated power grids. *Electrical Power and Energy Systems* 2019; 104; 744–771.

[22] CP Jesuthanam, S Kumanan and P Asokan. Surface roughness prediction using hybrid neural networks. *Journal Machining Science and Technology* 2007; 11;2; 271-286.

[23] MA Hannan and Azah Mohamed. PSCAD/EMTDC Simulation of Unified Series-Shunt Compensator for Power Quality Improvement. *IEEE Transactions on Power Delivery* 2005; 20; 2; 1650-1656.

[24] Ahmet Teke, K Cagatay Bayindir, M Emin Meral and Mehmet Tumay. Power quality improvement with an extended custom power park. *Electric power system research* 2009; 553-1560.

[25] Jun Young Bae, Youakim Badr, Ajith Abraham and A Takagi-Sugeno. Fuzzy Model of a Rudimentary Angle Controller for Artillery Fire. *Institut National des Sciences Appliquées* INSA-Lyon, F-69621, pp.1

[26] Mahesh, A Patel, Ankit R Patel, Dhaval R Vyas and Ketul M patel. Use of PWM Techniques for Power Quality Improvement. *International journal of Recent Trends in Engineering* 2015; 1;4;121-129.

[27] Ravi Kumar SV and S Siva Nagaraju. Simulation of D-STATCOM and DVR in power systems. *ARPN Journal of Engineering and Applied Sciences* 2007; 2; 3; 7-13.

[28] Sidhartha panda and Narayana Prasad Padhy. Optimal location and controller design of STATCOM for power system stability improvement using PSO. *Journal of the Franklin Institute* 2008; 345; 166-181.

[29] Tavakoli Bina M, MD Eskandari and M Panahlou. Design and installation of a 250kVAr D-STATCOM for a distribution substation. *Electric power system research* 2005;73; 3; 383-391.