Adaptive RNN with CSOA controlled based MMC-DSTATCOM for PQ enhancement in Distribution System

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Abstract: In this paper, a hybrid convergence method is used to evaluate the development of PQ in a distribution device. For PQ analysis, a D-STATCOM-based Modular Multilevel Converter device is being analyzed. This proposed hybrid adapter is named as the Adaptive Recurrent Neural Network with a Crow Search Optimization Algorithm (ARNN-CSOA), which is used for Modular Multilevel Converter (MMC) optimization based on the device D-STATCOM. The proposed D-STATCOM advanced method will now go by providing a fast watt controller with invisible power to compensate for loads, modern day imbalances, flicker power reductions and voltage regulation. The proposed hybrid control strategy is to maximize the power of participation through the RNN approach. By using the proposed hybrid adapter method, the PI controller barriers are identified in advance to deliver appropriate MMC based DSTATCOM action. The proposed process learns all types of switches for mechanical problems such as DC power, real and active power. Based on the proposed procedure, the appropriate MM-based D-STATCOM cones are produced and obtain the correct results. The proposed method employed in the MATLAB / Simulink platform and is associated with different PWM methods such as SVM and ANN process.
Keywords*:* Recurrent Neural Network, Crow Search Optimization Algorithm, Support Vector Machine (SVM), Artificial Neural Network (ANN) , MMC, D-STATCOM, PQ analysis.

1. Introduction

Normally, For successful operation and quality product delivering Power Quality (PQ) is essential. The increase in application of electronic loads and regulators are delicate to the quality of power can make severe economic outcomes and of revenue loss to every year. Poor PQ can cause failing of apparatus performance, voltage disproportion, sag and flicker problems, harmonics, standing waves and resonance – are few of the matters that horribly affect construction and its quality heading to huge failure in terms of energy, product and impairment to apparatus (Pourya sarvghadi, 2018; Hamed Heydari-doostabad, 2018; Suresh Kumar, 2018; Balamurugan, 2020). Thus,it develops imperative to be conscious of excellence of strength grid and the variation of the excellence constraints from the norms/trendy such as IEEE-519 preferred to stay clear of failure or apparatus damage. Recently, PQ issues are frequently focused on the Distribution System (DS) because this is receiving additional consideration as reliability is anxious. The PQ subjects are achieving an apprehension due to the boost in number of approachable loads (Xuzhu DON, 2018; Aroulanandam, 2020). Experience has revealed that the maximum of the PQ problems in the distribution system are voltage shortage, boosting the voltage, harmonics, flicker, imbalance and so on (Naruttam Kumar Roy, 2011; Ganesh Prasad Reddy, 2012; Hosseini, 2010, Latchoumi, 2020).

Up to now, many FACTS equipment or a mixture of them are given to progress power quality (Om Prakash,2016; Shareef, 2014; Herbert, 2015; Suryajitt,2014).The above methods can solve and decrease the trouble related to PQ issues. But, D-STATCOM is one of the utmost promising FACTS devices which is used for enlightening the PQ problems (Ezhilarasi, 2020; Deepthi, 2020). This is founded on the voltage source converter (VSC) which be able to switch active and reactive power through grid corresponding to its regulator system. At the point of common coupling (PCC) the device is connected in parallel to grid for the aim of power factor correction, voltage regulation, harmonic reduction also load balancing (Anuradha, 2011; Molina, 2006; Sixing, 2013). The prospective applications of D-STATCOM are voltage regulation,load balancing, power factor correction and harmonic reduction. When compared with the SVC, the DSTATCOM has faster response time and solid structure (Rakesh, 2016; Garikapati, 2020).

Many manage methods are testified such as Budeanu theory, fryze theory, IRP theory, p-q concept and extension p-q concept and many others. For these type control techniques are included to obtain gating signals for the Insulated Gate Bipolar Transistor (IGBT) strategies used in current controlled voltage source inverter (CC-VSI) working as a DSTATCOM employed in the D-STATCOM (Chandan Kumar, 2014; Bhim Singh, 2014).To set up the strength element correction ,harmonic elimination and load balancing skills of the DSTATCOM system, multilevel inverter/converter is utilized to create the gating signals. (Chandan Kumar,2014;

Sneha, 2020). Different types of converter/inverter design are presented such as cascaded H-bridge inverter, fly back capacitor type converter, n-level inverter, star and delta type converter and so on. Recently, researchers and engineers have attention on the modular multilevel converter (MMC) due to its high-power applications and more idegrees iof freedom for control (Nasser Ahmed, 2016).

2. MMC based D-STATCOM for PQ Enhancement

This paper expresses that the RNN with CSOA based MMC control of-DSTATCOM can be viably utilized to improve the nature of intensity scattered to customers through 3-phase 4-wire distribution system. Under static, dynamic and consolidated stacking prerequisites the compensation capability of DSTATCOM is verified with unbalance nonlinear and linear hundreds. The d-q-0 parts of burden flows are utilized for growing compensator contemporaryfor DSTATCOM. The RNN with CSOA is employed for producing the switching pulses crucial for MMC used in the DSTATCOM. Several good judgment blocks of the synchronous reference body theory(SRFT) governor manner and RNN with CSOA are defined in the following section.

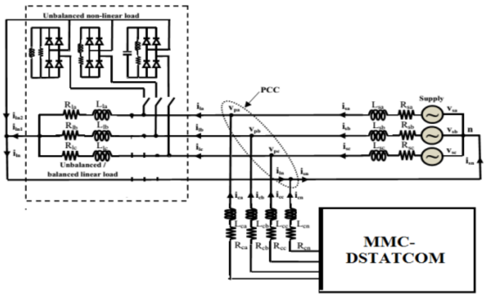


Figure 1. Structure of proposed method based MMC with D-STATCOM

Here, the MMC based D-STATCOM is described and illustrated in the Fig. 1. It is connected between the sources and load to mitigate the PQ issues. The related PQ issues are considered to analyze the system such as decline of voltage to lower level and becoming voltage in greater intensity.Moreover, the performance of the MMC with D-STATCOM is analyzed under the stable and unstable condition. The level of the MMC converter is specified as the 17^{th} level. To verify the 17^{th} level of MMC, the level of turnout of voltage is checked. The operation and regulator strategy of MMC based D-STATCOM is analyzed and mentioned in the following.

2.1. Modular Multilevel Converter

Here, the general description of MMC is defined and the controller strategy of MMC based D-STATCOM is analyzed. MMC have recently focused as substitute solution to conventional multilevel converters in intermediate voltage claims. It provide a feasible approach forerecting a reliable and cost operative STATCOM, with amplified number of levels proficient of removing the coupling transformer and substituting it with inexpensive reactors to permit a power exchange through the power system. A governing approach founded on the instantaneous power theory is established for mining the compensating current signals. Then, an adaptive technique based current regulator technique is presented for the MMC, built on the RNN with CSOA control method. Keeping the deposited energy in all of the legs stable a suitable switching modulation system is applied to the MMC, even if the converter currents are unbalanced and the grid voltages are slightly slanted. Analytical methods are consequent to demonstrate the precise mechanism of the DC-link voltage balancing. In the Fig.2 represents the structure of MMC, which has the sub module (SM) configurations. Normally, the sub modules contain two diodes, two IGBT switches and capacitor. For the three phases A, B, and C has six arms has the sub module circuit and each one is constituted by a number of SM. In a MMC, SMs are connected in series using several steps of output voltage. With simple three level MMC reference it is shown here how the voltage levels are generated However, splitting capacitor voltage control issue is accompanied in MMC. Reference grants an MMC-based STATCOM framework, yet the dc voltage adjusting representative has not been reasonably talked about. The supposed “arranging voltage of capacitor,” which receives the charge or release of every SM by utilizing dc-connect voltage rate and current bearing, can proficiently adjust the unmistakable dc voltage of chopper cells, then again the coordinating amongst the higher appendage and decrease appendage of every fragment pair isn’t clear.Further more, the control policy using circulating current for dc voltage switch cannot be directly functional to triple-phase triple-wire MMC-based D-STATCOM, as the three independent essential lmechanisms of upper and lower limbs may not withdraw out all the time to fulfill with KCL law. In this paper, MMC based D-STATCOM is proposed to study the PQ issues on the distribution system. Here, the levels are increased and the output voltage level of the MMC is denoted. decoupled recompensing current control, circulating current governor, and dc voltage regulator are the three parts composed in control strategy. In next section, The particulars of dc voltage regulator are presented.

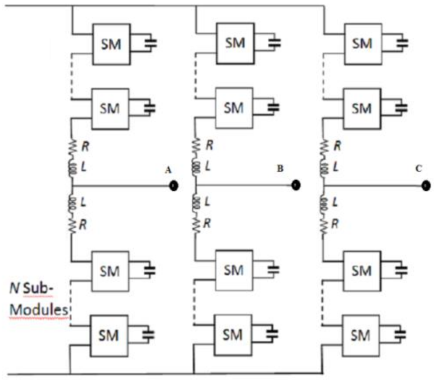


Figure 2. Structure of Modular Multilevel Converter

3. Control Strategy of MMC based D-STATCOM

To analyze the current performances, the AC voltage of the circuit is defined. Initially, the single segment ac voltages for the decrease and top leg is certain as,

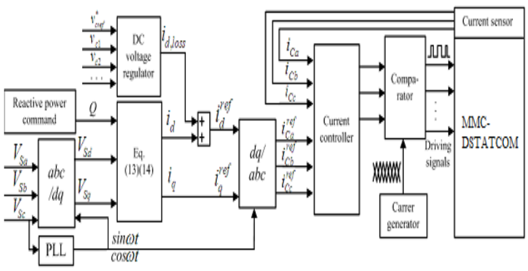
$$V_{p,k} = \left(\frac{E}{2}\right) - V_k - \left(\frac{V_H}{2}\right) \quad \textbf{(1)}$$

$$V_{n,k} = \left(\frac{E}{2}\right) + V_k - \left(\frac{V_H}{2}\right) \quad \textbf{(2)}$$

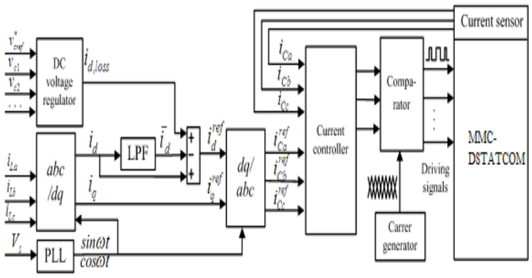
Where $V_{p,k}$ and $V_{n,k}$ are the components to yield compensating current and circling current, respectively. Conceding to (1) and (2), the connection between recompensing current and ac output voltage are attained by,

$$2V_{S,k} + L\frac{di_k}{dt} + R * i_k - 2V_k - 2V_{po} = 0 \quad (3)$$

In 3-phase 3-wire system, the zero-sequence current does not exist. The third term in (4) should be neglected as the zero-sequence mechanisms in source voltage and converter ac voltage do not disturb the output current of the converter. While attractive positive and negative- sequence workings into account two proportional and critical (PI) regulators with constraints of and for close-loop current manage are introduced. Fig. 3 Shows the control strategy of MMC with D-STATCOM controller.



(a)



(b)

Figure 3. Control strategy of MMC with D-STATCOM controller (a) Current Compensation Loop and (b) Voltage regulation Loop

$$V_{S,d} + L\frac{di_d}{2dt} + \frac{R}{2} * i_d + \frac{\omega L}{2} * i_q - V_d = 0 \qquad (4)$$

$$V_{S,q} + L\frac{di_q}{2dt} + \frac{R}{2} * i_q - \frac{\omega L}{2} * i_d - V_q = 0 \qquad (5)$$

$$V_{S,0} + L\frac{di_0}{2dt} + \frac{R}{2} * i_0 + \frac{\omega L}{2} * i_d - V_{p,0} = 0 \qquad (6)$$

To control the circulating current, PI regulator is utilized. The controller PI is performed with the help of proposed RNN and CSOA method. The difference among two equations relationship among circulating current and ac output voltage,

$$2L\frac{di_{H,k}}{dt} + 2R * i_{H,k} + V_{H,k} = 0 \quad (7)$$

The order voltage for creating coursing current is acquired by giving a relative controller the parameter,

$$V_{H,k}^{*} = \rho_H^{p,i}\left(i_{H,k}^{*} - i_{H,k}\right) \qquad (8)$$

Substituting into (1)& (2) ,the order voltages for two legs in a single stage are accomplished. Subsequent to thinking about the particular control with fringes for air conditioning voltage, the order voltage for every chopper cell is given by

$$V_{p,k,j}^{*} = \frac{E}{2N} - \frac{V_k^{*}}{N} - \frac{V_{H,k}^{*}}{2N} + \delta V_{p,k,j}^{*} \quad (9)$$

$$V_{n,k,j}^{*} = \frac{E}{2N} + \frac{V_k^{*}}{N} - \frac{V_{H,k}^{*}}{2N} + \delta V_{n,k,j}^{*} \quad (10)$$

According to the meaning in instantaneous reactive power theory, the instant active power and reactive power is shown as follows,

$$P_s = V_s^d i_d = \sqrt{3Vi_d} \qquad (11)$$

$$Q_s = V_s^d i_q = \sqrt{3Vi_q} \qquad (12)$$

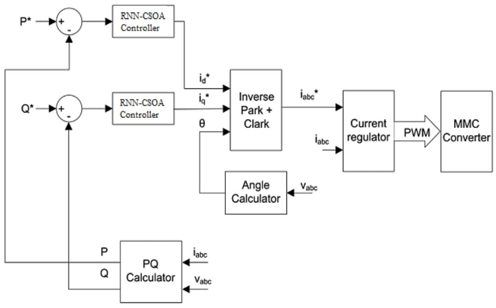


Figure 4. Control structure of RNN with CSOA for current, real and reactive power

The above Fig.4 shows the general control structure of the proposed. It has mentioned about the real and reactive controller as well as current controller also. To control the flow of the current and voltage, the RNN with CSOA is utilized. On the other hand, the real and reactive power optimization is also done over the proposed method. The detailed explanation of the RNN and CSOA is explained as below section 3.1.

3.1 Crow Search Optimization Algorithm

Alireza Askarzadeh developed a met heuristic algorithm, named crow search optimization algorithm (CSOA) for resolving constrained optimization problems based on the smart behaviors of crows. The working code of CSOA is based on the idea that crows can hide spare foods as well as recover them as and when essential. They are also acknowledged to commit thievery, theft other birds food.Crows which commit this performance take extra protections to avoid being a forthcoming victim and can in fact, govern the safest hideouts to guard their food items being stolen by others.

The basic principles of CSOA are listed as follows:

- Crows live in group form.
- Crows remember the site of their concealing spots.
- In Thievery, Crows follow one another.
- Crows defend their reserves from being stolen with the aid of probability.

In the paper, the CSOA is utilized to optimize the gain constraints of the PI controller. To optimize the gain parameters automatically, the voltage, current and real and reactive power is to be controlled with the assistance of the proposed method. Here, the voltage loop, current loop besides real & reactive power control loop is together analyzed with the help of proposed method. For the voltage control loop, the actual voltage and reference voltage is given as the input of the control strategy. After that, the error voltage is determined, that is applied to the input of the PI controller. To minimize the error functions, the Kp and Ki gain parameters are tuned optimally. Regarding that, the gain parameters are randomly generated and the error is minimized. The detailed step wise process is mentioned in flowchart.

3.2 Recurrent Neural Network

The RNN is one of the Artificial Intelligence (AI) technique, which is utilized for the prediction and error minimization. The RNN has four layers namely, input layer, hidden layer, context layer and output layer respectively. Generally, two context layers has been used in RNN: the Elman context layer and the Jordan context layer, both with some alterations from the original Elman and Jordan recurring neural networks. The Elman context layer varies from the novel Elman RNN because the two setting neurons attain inputs from the output of the hidden layer afterward a postponement of one time unit, and as of itself (Amit Kumar, 2018; Azhagesan, 2018; Raveendra, 2019; Balaji, 2019; Sampathkumar, 2020; Jayanthiladevi, 2018). In the Jordan background layer the change is that setting neurons accomplish contributions from the yield mistake of the system after a postponement of one time unit and from itself There are two neurons with self-inputs in both setting layers. .For forecasting time sequences in the output layer, we require just one neuron. It has been stated that all data point in a time sequence is strongly dependent on the immediate earlier two values so we use two neurons in enter layers. In the output layer, the Jordan context layer and the Elman context layer linear initiation function has been used. In the hidden layer, sigmoid beginning function is used. In this paper, the output of the CSOA is designed as the datasets and trained through the RNN system. It predicts the accurate optimal gain parameters for the PI controller. Hence,To take input-output association from information highlight vectors RNN is used as a part of this technique. Fig. 6 demonstrates the structure of RNN with one shrouded layer.In this Fig.6, N and S are the numbers of input, hidden neurons, and output, correspondingly.

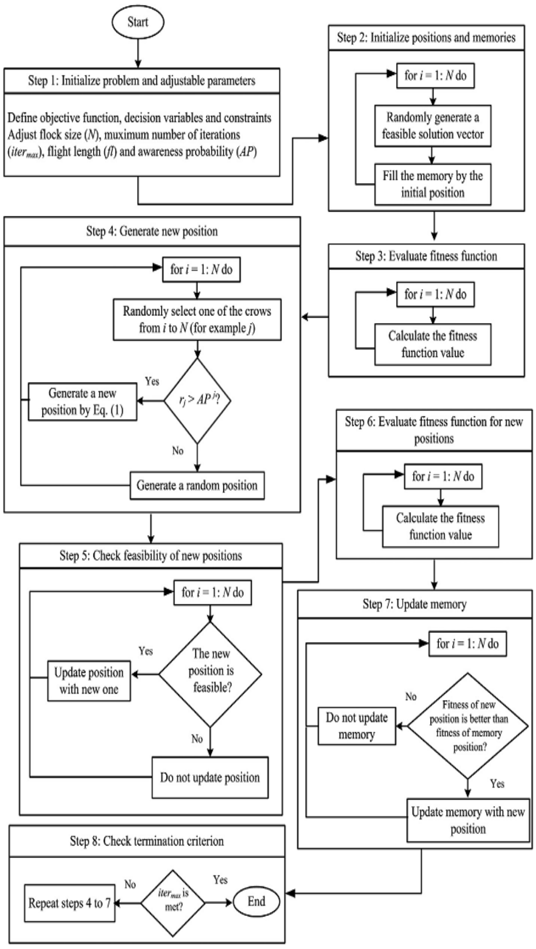


Figure 5. Flow chart of CSOA algorithm

The repetitive neural system can be verbalized by the accompanying Eqns. (13) and (14).

$$h_{oi} = f\left(\sum_{j=1}^{R} iw_{ij}.x_j - h_{bi}\right), \; for\, i = 1,2,\ldots,N \qquad (13)$$

$$y_i = f\left(\sum_{k=1}^{N} hw_{ik}.h_{ok} - o_{bi}\right), \; for\, i = 1,2,\ldots,S \qquad (14)$$

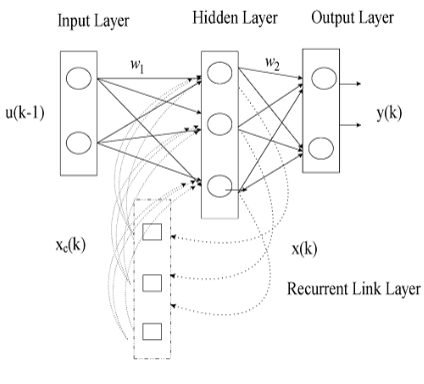


Figure 6. A RNN with four layers

Where, f is an activation function, iw_{ij} the connection weight from the j^{th} node in the input layer to the i^{th} node in the hidden layer, and hw_{ik} is the connection weight from the k^{th} node in the hidden layer to the i^{th} node in the output layer. It is required to oversee the course of action regarding number of layers and neurons in layers .A system with a structure that is more mind boggling than required may over fit the preparation information. The fitness function in the training procedure the Sum Squared Error (SSE) performance function is given as Eqns. (15) and (16).

$$SSE = \sum_{k=1}^{Q} E_k \qquad (15)$$

Where, $$E_k = \sum_{i=1}^{S} \left(y_i^k - d_i^k \right)^2 \qquad (16)$$

Where, Q is the number of training examples, y_i^k is the actual output of the i^{th} input when the k^{th} training sample is used, and d_i^k is the desired output of the i^{th} input when the k^{th} training sample is used.

Short process of RNN, initialize RNN structure, as well as the parameters in the CSOA. The parameters are randomly generated the vary of [-10, 10]. Decode the close to greatest answer of the RNN. For near optimal solution use the BP algorithm for searching. It can be set as the current search result, If the search result is better. The global optimum is to be recorded. Output is the current search result. In the masked layer, the quantity of neurons is limited to whole number qualities. The parameters comprising loads and inclinations are allowed to recognize the veritable characteristics. These parameters are refreshed by the crossbreed count..Higher accuracy rateand lower SSE are favored. Furthermore, To evaluate the exhibitions of the preparation calculations the amount of accentuations required to accomplish the last results is in like manner used.

4. Results and Discussions

Here, the proposed strategy is executed in MATLAB/Simulink Stage. The proposed RNN with CSOA method works as the optimal control algorithm of MMC based D-STATCOM device for evaluating the optimal gain and pulse capability. Finally, the results were compared with traditional methods. It works as quick compensating source for reactive power that was convenient on the distribution power system to diffident voltage deviations similar to voltage swells, sags and voltage flicker along with unevenness produced by rapidly varying reactive power demand. The continuing PQ enhancement/ reliability prediction in the development process is helpful to promote the development capability of D-STATCOM device and guarantee a more reliable controller.

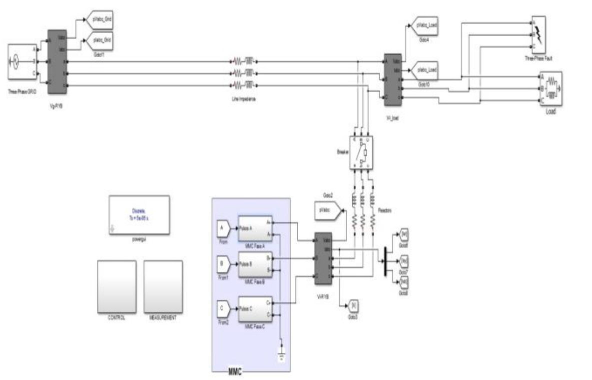


Figure 7. Simulation modeling of proposed method with MMC based D-STATCOM

Fig. 7 is the MMC based D-STATCOM device in the Simulink platform. For both linear and nonlinear three phase loads in balancing and unbalancing circumstances replicated results from a MATLAB model are offered. A stage is disengaged from t=0.02s to t=0.06s to make the unsettling influence in the electrical framework for the two sorts of three stage. The grid currents are sinusoidal and balanced flat beneath unbalanced loads.Fig.8 shows that the voltage sag analysis of the proposed and existing methods.

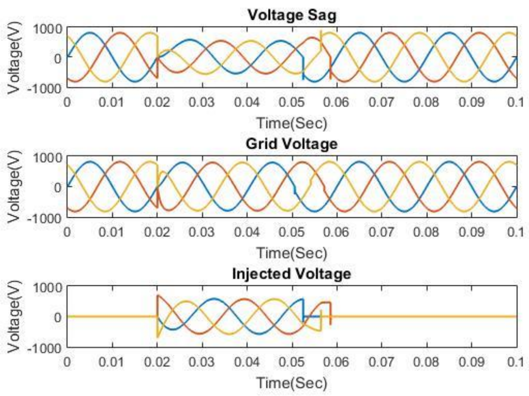
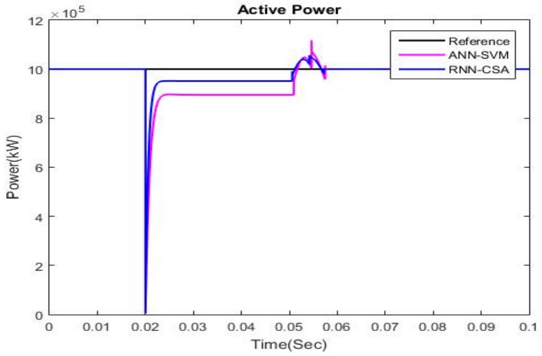
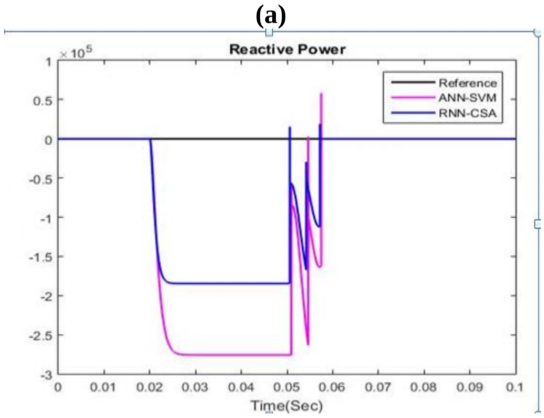


Figure 8. Voltage Sag Analysis



(a)



(b)

Figure. 9 Analysis of (a) Active power and (b) Reactive power

Fig.9 shows that the active and reactive power of the proposed and existing methods. It can be easily evaluated the reactive power of the system. Thus,to mitigate the sag drawback D-STATCOM works in electrical phenomenon mood supply power to the system. Whereas, within the case of voltage swell, the modulation index also determined, creating the D-STATCOM work in an inductive mood by injecting power from the system. Accordingly, the voltage at PCC is restored to its face value. Fig. 10.depict the swelling mitigation method.

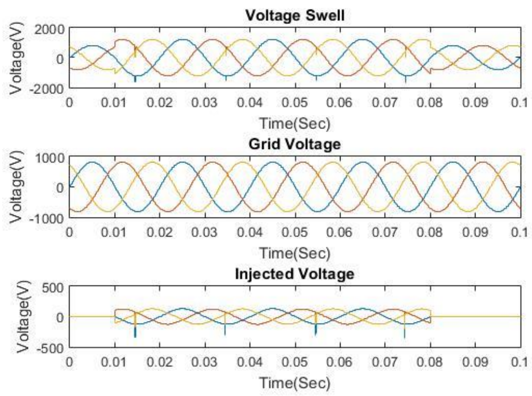


Figure. 10 Voltage Swell Analysis

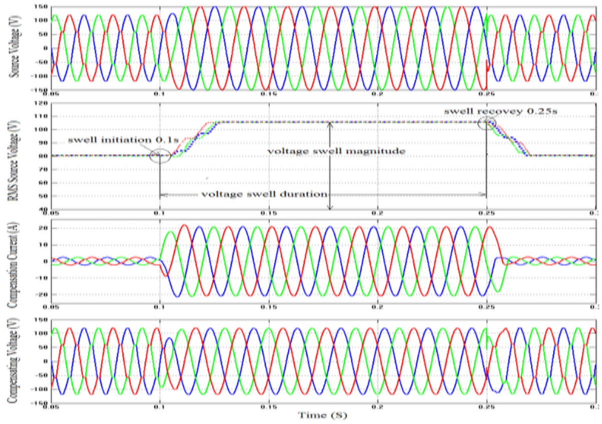


Figure. 11 Analysis of Compensation Voltage and Current

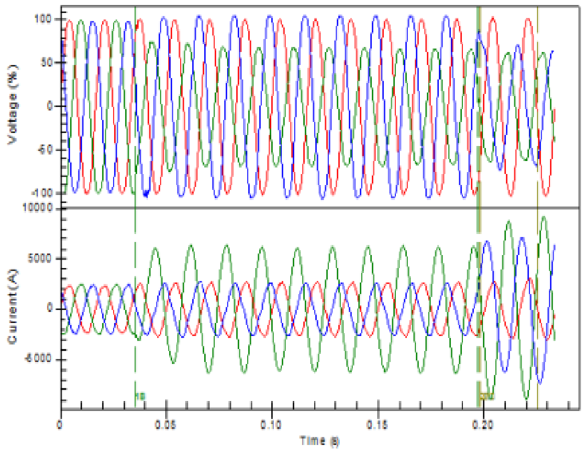


Figure.12 Analysis of Voltage and Current in voltage distortion period

Fig. 11 shows voltage and current waveforms during compensation period. Whereas Fig. 12 shows the voltage and current waveforms during distortion period. Fig. 13 shows the comparison of voltage under sag and swell conditions.

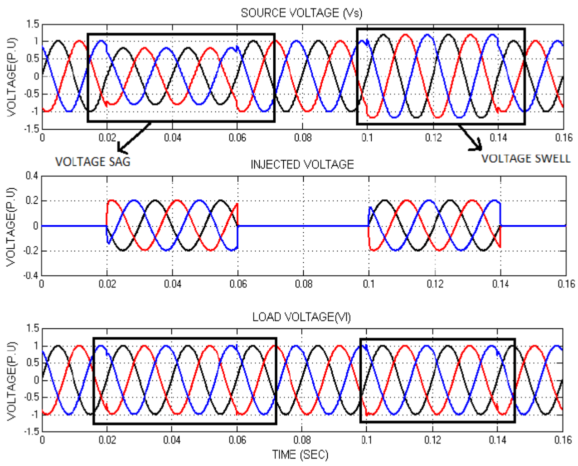
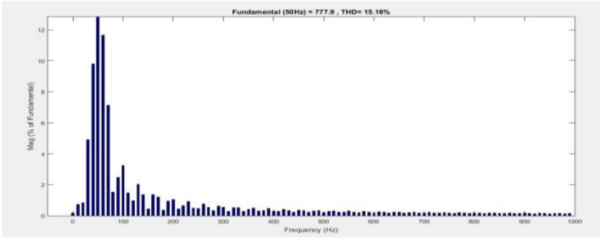


Figure.13 Comparison analysis of Voltage Sag and Swell



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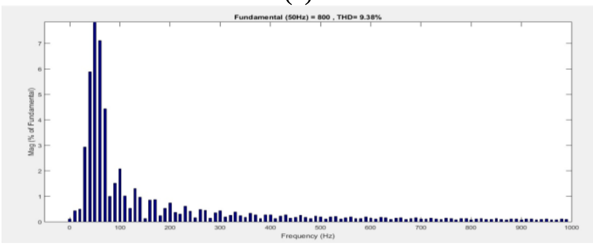

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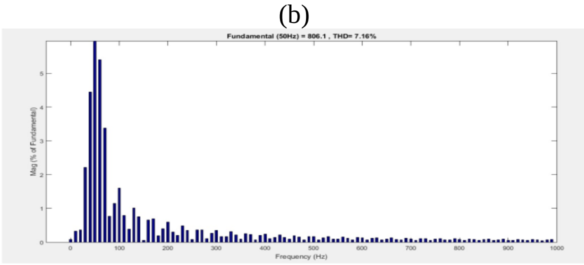
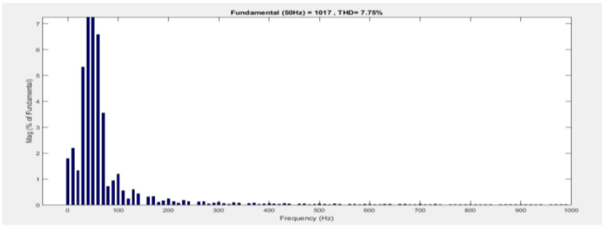
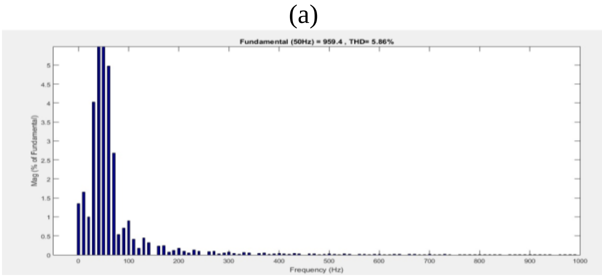


(c)

Figure.14 THD analysis of (a)ANN (b) SVM and (c) proposed method under voltage sag condition



(a)



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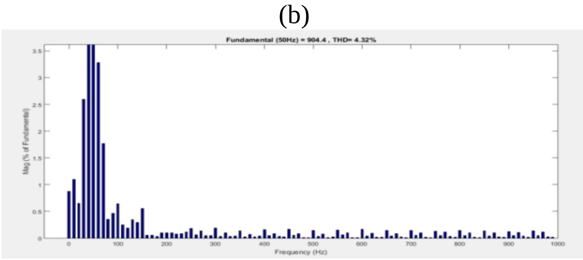

(c)

Figure.15 THD analysis of (a) ANN (b) SVM and (c) proposed method under voltage swell condition

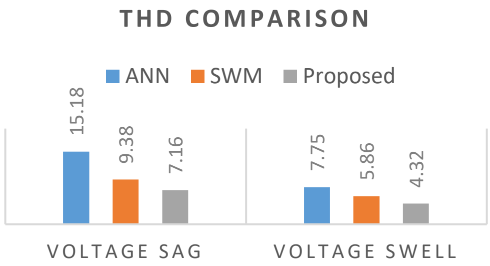

Figure. 16 THD comparison of ANN, SVM and Proposed methods

Here, the nonlinear loads are connected and tested with the different scenarios such as voltage sag, swell and flicker period. The performances of the system are resolute and their voltage, current, genuine and reactive power is evaluated. Initially, without D-STATCOM performances are monitored after that, certain PQ issues are engendered and tested with the proposed MMC predicated D-STATCOM. It lags the supply voltage and consists of harmonics. During this period, reactive power from the grid is drawn by cumulated load. After the connection of compensator, the proposed MMC predicated D-STATCOM in a split second commencements its daily schedule and modifies the lopsided inventory current into adjusted and sinusoidal. In additament, the stockpile current is culminated in-stage with voltage, which is verbalized with in Fig. 13. The unbalanced non-sinusoidal source current has a THD of 15.18%. After linking the DSTATCOM, THD of the compensated supply current declined to 7.16% which is conspicuously optically discerned from Fig. 14.While utilizing other methods, the THD in voltage sag conditions are 15.18% and 9.38% respectively. In the voltage swell conditions, the THD performances are illustrated utilizing the FFT analysis depicted in the Fig. 15. Fig. 16 shows the THD evaluation of both Voltage Sag and Voltage swell cases for the ANN, SVM and Proposed methods.

5. Conclusion

In this paper, MMC predicated D-STATCOM controller is derived by utilizing Adaptive RNN with CSOA method. The proposed method is implemented in MATLAB/Simulink platform and tested with the sundry PQ subjects, such as voltage swell, Sag and flicker conditions. The MMC predicated D-STATCOM is to be efficacious to mitigate the PQ issues under the sundry levels. The MMC is assigned on the higher caliber (i.e., 17th level) to achieve the precise results. In additament, compensating reactive currents and the dynamic reply of the system will avail the mitigation of voltage sag, swell and flicker. The corresponding analysis of genuine and reactive potency, dc link voltage is additionally analyzed. Conclusively, the FFT analysis is utilized to analyze the THD performances of the system. The proposed method achieves the THD as 7.76%,5.86% &4.32% and the other methods are 15.18%,9.38% &7.16 respectively. It shows that, the proposed method is gives the less THD computation and optimal results when compared with the traditional ANN and SVM methods.

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