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Research Article

Hybrid Controller and DSTATCOM with Hybrid Technique Optimized and Integrated the Hybrid Power Generating System

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Abstract

In order to solve both issues of the fluctuation in power and quality of power in the grid connected hybrid power generating system, a novel topology-based hybrid controller designed in the system where Robust phase-locked loop (PLL) based hybrid VSC controller to adjust the DC-link voltage and AC side current in the hybrid power generating (HPG) system and another side Distribution Static Compensator (D-STATCOM)device with a hybrid technique has been utilized to improve power quality (PQ) of grid connected HPG system. The hybrid technique is a combination of Recurrent Neural Network (RNN) with Cuckoo search (CS) algorithm. For analysis of the performance of the proposed controller shown in the two stages, in the first stage, the PLL-based hybrid voltage source converter (VSC) controller is designed to mitigating power fluctuation at DC-link by applied a battery energy storage system (BESS) on the DC side. In the second stage, the PQ issues like sag, swell and interruption analyzed and reduced the harmonic distortion. Finally proposed hybrid system has been modeled in MATLAB/Simulink and the simulation results as obtained are compared with an existing controller.

Keywords: Cuckoo search (CS) algorithm, D-STATCOM with RNN, hybrid power generating system, renewable energy, energy storage system, power quality.

1. Introduction

Nowadays, the combined use of Renewable Energy Sources (RES) likes solar and wind energy is widely used to replace traditional energy resources and, as a result, to reduce fossil fuel burning. Furthermore, RES generate energy without emitting greenhouse gases or carbon dioxide (CO2) into the atmosphere, which is beneficial to the environment they also do not pollute the soil or the water. As a result, proper use of the hybrid power generating (HPG) system such as wind and photovoltaic (PV) system with BESS should be the future plan to fulfill energy demand. Although the power generation of RES is influenced by factors such as temperature, irradiance, and wind speed Due to variations in these environmental inputs are reflected in the power fluctuation on the DC-link so the tremendous difficulty of keeping constant power on the DC-

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link of HPG system. Therefore these resources must be supported with energy storage devices to be stable and reliable the HPG system output.

A HPG system is becoming more widely used in conjunction with the concepts of distributed generation and micro grids, in which several sources of renewable energy likes solar energy, wind energy, fuel cells, and so on, are combined with another distributed nonrenewable energy generator systems in a harmonized way to meet the need of a specific domain and load [1]. Furthermore, by connecting the HPG system to an energy storage system such as a battery, when there is no sunlight or wind, and no power is generated, the surplus energy generated by the solar system or wind turbine can be stored and used. Consequently, HPGS is more efficient in all operating situations than a single renewable technology. On another basic level, there are several types of HPG systems as grid connected or standalone, as well as by the types of renewables and non-renewables employed, as well as the type of storage element employed if one exists [2]. HPGS and microgrids with higher load balance of demand and optimization of dispatch are considerably enabled by emerging smart buildings with sophisticated communication, processing power, and control [3]. Modelling of renewable energy systems on microgrids is frequently used to assess micro-grids' dynamic behavior while connected to the power grid in order to enable such integration. The optimum configuration and performance of an HPG system in autonomous mode includes an examination of the changing environment of renewable energy sources, as well as the system's technical performance due to the implementation of a comprehensive control method for extracting the maximum required power to fulfil load demand while maintaining the storage element's required SOC [4]. Various learned who have built extremely small simulation models with a specific attention on the dynamic and technical scale study of HPG systems submitted their attempts to address this issue [5].

The utilization of energy storage devices in conjunction with a bidirectional DC-DC converter connected to the DC bus in order to manage power discussed in [6]. The controlling power and coordinating activities ensure that the microgrid system operates reliably under a variety of operational situations. [7]. DC microgrids provide for more versatility in control scheme execution, ensuring that DC microgrid voltages remain within acceptable limits and that system power balance is maintained in both islanded and grid linked modes [8]. The various strategies of bidirectional DC-AC converter control discussed in [9]. The state of charge (SOC) of the battery storage unit is utilized to determine safe charge and discharge limitations. The slop of SOC also indicates the battery's charge and discharge rate [10].
While in the other aspect, Power Quality (PQ) problems are more complex in the power system. Power conditioning devices based on power electronics can be an effective way to enhance the quality of power delivered to distributed generation. PQ is a term that combines voltage and current quality to describe how far voltage or current differ from idyllic waveforms. The idyllic waveforms have a sinusoidal shape with a definite amplitude and frequency that are equal to the rated or nominal values [11]. As a result of these renewable resources' variable power density, unstable PQ disturbances such as voltage sag, swell and voltage interruption can arise. They differ from the effects of load acceptance and rejection, electronics switching, and other factors. In power systems, voltage signal sag, swell is typically caused by the sudden acceptance/rejection of a large nonlinear load and induction motors, transformers, etc [12]. PQ disturbances caused by either the source or the load side can cause a variety of operational issues such as malfunctions, electrical equipment failure, instabilities, and so on [13]. The Hybrid

System (HS), which aims to improve the quality and reliability of power supply, may increase the frequency of power outages in the future [14]. However, with the DG connected to the utility grid, there are numerous issues to be seriously and critically considered, such as resource islanding and PQ disturbances. The cause of power system disturbances can be identified and improved by monitoring and analyzing power quality before they cause interruptions [15]. These disturbances may diminish with distance from their source, but depending on the grid layout, they can potentially amplify [16]. Furthermore, PQ issues can result in a loss of output, an increase in labor-related losses, a rise in the amount of defective goods, late shipments, and a failure to fulfil manufacturing requirements. As a result, PQ analysis has become a critical consideration when making decisions on how to enhance, operate, manage, and grow power systems [17]. As a result, the advancement of signal-processing techniques has become a major concern for PQ. The findings obtained with various detection algorithms, however, may be influenced by system noise [18]. Then, in order to reduce the grid's PQ problems, various controllers such as the S-transform (ST), Wavelet Transform (WT), more other controllers like fuzzy logic controller, artificial neural network (ANN), neural network (NN), modular neural network (MNN), probabilistic neural network (PNN), genetic algorithm (GA), particle swarm optimization (PSO) and others are used to train and improve the PQ with various techniques. Customers' power electronic equipment has become more sensitive to power line carrier signals and other grid connected devices as a result of equally important PQ concerns [19]. As a result, grid-interfacing converters have tended to combine PQ improvement and power systems in order to adapt to future grid uses [20].

2 Modelling of proposed inverter control structure

Fig. 1 shows a VSC based on a typical voltage control system on grid voltage. The proposed VSC converts DC-link voltages to three-phase AC voltage while maintaining unity power factor. The proposed VSC inverter is driven by a gate drive circuit that gates the control signal from the abc phase PWM generator, with

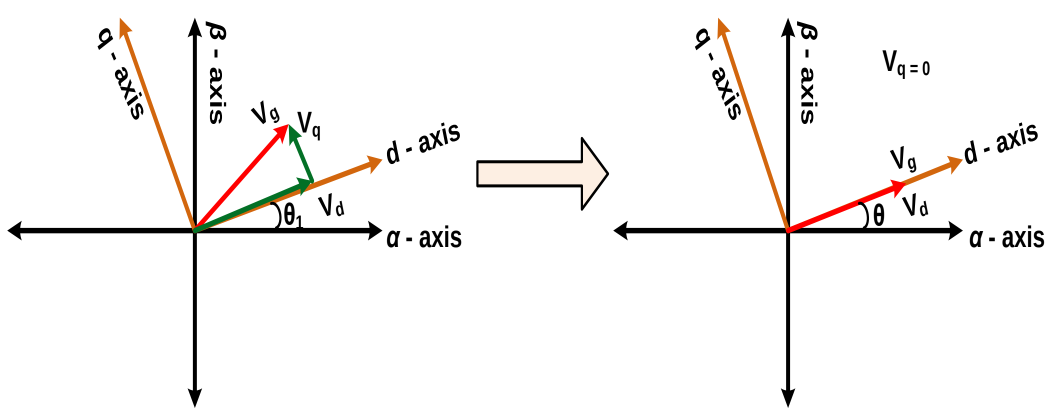

Fig. 1 Phasor represantation of grid voltage on two coordinate axis

the input to the PWM being the control signals from the controllers' outputs. The mathematical model of VSC that is translated into dq frame show in [28].

$$\begin{cases} L_f \dfrac{d\,i_d}{dt} = V_d - V_{td} + \omega L_f i_q \\ L_f \dfrac{d\,i_q}{dt} = V_q - V_{tq} + \omega L_f i_d \\ V_{dc} \dfrac{d\,V_{dc}}{dt} = V_{dc} I_{dc} - V_{td} i_d \end{cases} \quad (13)$$

Where V_{td} and V_{tq} are the point of common coupling (PCC) voltages in the *dq* co-ordinate; V_d and V_q are the modulation voltages in the *dq* co-ordinate and i_d and i_q are the actual values of the current in the *dq* co-ordinate.

The proposed VSC control system utilizes two control loops: an exterior control loop that regulates the DC link voltage up to the appropriate limit, and an internal control loop that regulates the active and reactive current components of the i_d and i_q grid currents. Here three-phase current converted into two-phase currents in the αβ co-ordinate system with help of *abc* to *αβ* transformation and output will be i_α & i_β now it's transformed into *dq* co-ordinate with help of *αβ* to *dq* transformation and output will be i_d & i_q. The error signal between i_d and i_d* (MPPT maximum current) is input to the controller and on another side, the error signal between *iq* & i_q* is input to another current controller. To maintain a unity power factor, the i_q* reference is set to zero. The current controller's V_d and V_q voltage outputs are converted into $V_{abc\text{-}ref}$, the three modulating signals used by the PWM generator. The voltage and current controllers, as well as the PLL synchronisation unit, use a sample time in the control system. Pulse generators of boost and VSC converters use fast sampling times to obtain a suitable resolution of PWM waves [29-30].

In brief to more robust as the closed-loop modification is suggested (PLL). The coordinate system (Fig. 8) has *αβ* coordinate system and has a voltage space vector (grid voltage). Now let us the d-axes are miss align means it is misaligned along among the V_g space vector and as consequence the projection on the d-axis will give the V_d and V_g, so there is a V_g component also if it had been aligned along with V_g if d-axis has been aligned along with V_g then V_q component would have been zero, now this θ is the angle between the *αβ* coordinate and the *dq* coordinate due to some reason V_q is not zero then compares with the V_q it goes to negative and the PI controller will become active and θ change in such a direction that the input to the PI controller which is the error will tend to zero then V_q have will zero to V_q*. where if V_q* is equal to zero, therefore, V_g will tend to zero that means it will align the d-axes along the voltage space vector, and the value of θ will come out because the control action such that V_q here will become zero. So d-axes are aligned along the voltage space vector, this is a very robust mechanism because it is the close loop in which will filtering effect on harmonics, surges, spike, and such than uncertainties.

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3. Simulation results of hybrid power generating system

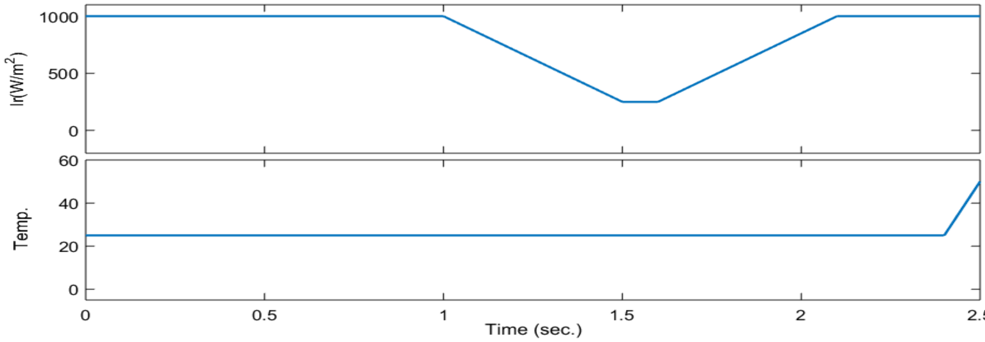
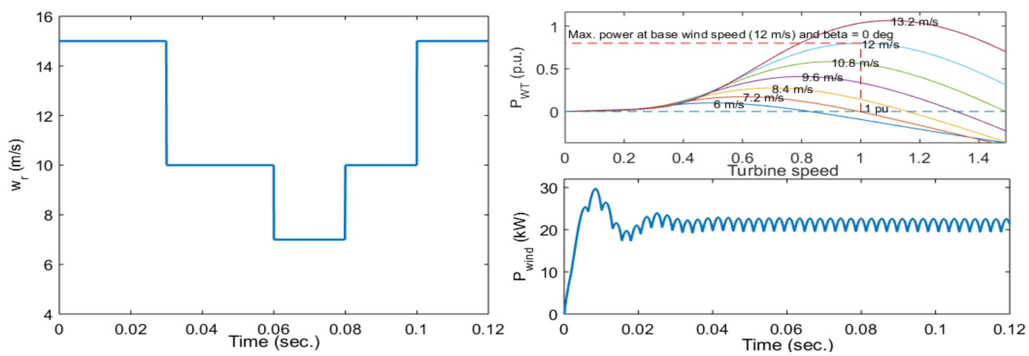


Fig. 2 PV irradiation and temperature



(a) (b)

Fig. 3 Wind speed and wind turbine power characteristic

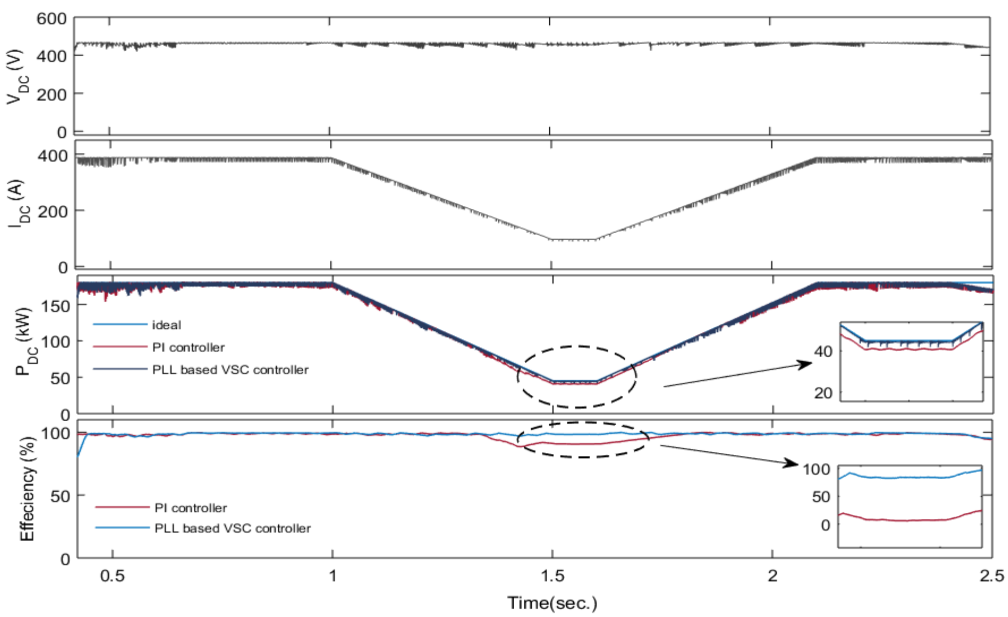


Fig. 4 DC-link voltage, current, and power under the proposed controller

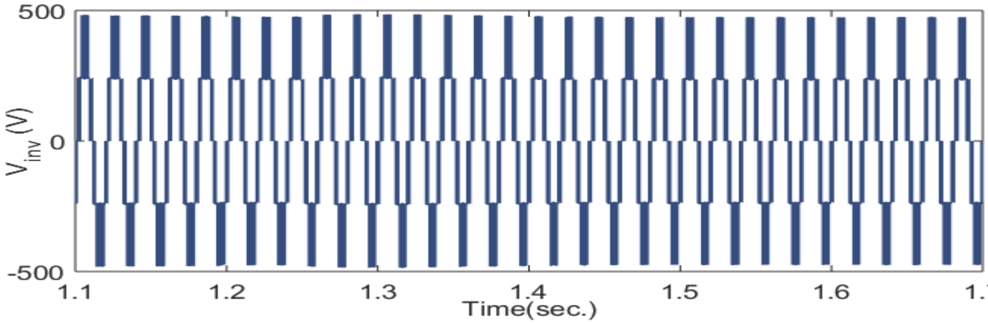


Fig. 5 Inverter output voltage.

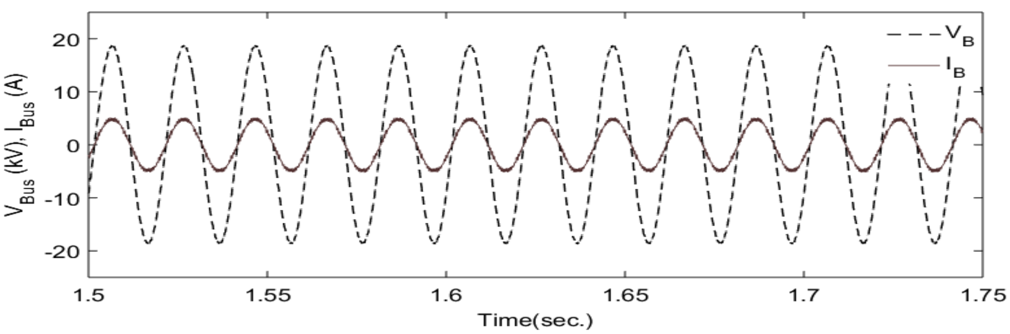


Fig. 6 Bus voltage and current

4. Discussion

In case first, a robust PLL-based VSC controller is designed to smooth the DC-link power. This controller synchronized the performance of the Inverter and MPPT in the Hybrid Power Generating System model, allowing the system to be stable and reliable. the controller can test under weather variation of environment and other situational conditions in terms of Fig. 10 and the operational event will be shown in Table 2, it can be seen that the irradiation of the PV array was 1000 W/m^2 until t = 1 sec. after that, the light radiation dropped to 250 W/m^2 up to 1.5 sec. and about to 0.1 sec. later, the irradiation gradually increases to 1000 W/m^2. Where the ambient temperatures maintain 25 ^{0}C from 0 to 2.4 sec. after that ambient temperature goes up from 25 ^{0}C to 50 ^{0}C during the time 2.4 to 2.5 sec. In Fig. 11(a), the wind speed is vary 7 m/s to 15 m/s during given time period. The power characteristic of wind turbine is shown in Fig. 11(b) where wind turbine generates maximum power at 12m/s of wind speed. On the AC side, the grid injected active power and reactive power are controlled by the d-axis and q-axis components of grid voltage and current with help of the proposed controller, the active power is set based on the actual requirement while the reactive power keeps at zero. The modulation index and duty ratio work together according to grid voltage and current to produce the PWM signals and also interlinks with the DC/DC bidirectional controller of BESS for smooth power to improve the PQ of the HPG system. Fig. 12 shows the voltage, current, and power waveform at DC-link under the PI controller and proposed hybrid controller, where the voltage across both capacitors C_1 and C_2 can be seen nearly constant during the performance of the system. Where the proposed controller gives better results than the PI controller as shown by the proposed controller-based DC-link voltage is smoother than the PI controller from 1.42 to 1.9 s. and gets smooth output power and current at the DC side. the performance of the whole system under the conditional situation with proposed hybrid controller where power at dc-link is performed according to this controller and compare with ideal power. The hybrid power generates system can be also analyzed according to this controller and it can be seen from the perspective that the efficiency of the hybrid control system is nearly 98% while the efficiency of the other unturned controller system is less than 50% of yellow's expectation. Figure13 shows the 3-level output voltage of the inverter is better performance than the PI controller. The single-phase bus current in phase with bus voltage and a unity power factor is maintained that fed maximum power into the grid is presented in Fig. 14. In case second, the voltage sag is described as a drop in voltage of 10% to 90% during a half cycle or more. Fig. 15 (a) depicts the voltage sag signal. The proposed controller is used to perform the mitigation. The DC-link voltage can change because of load connection/disconnection then the supply side voltage sag/swell appears which will affect the system performance so the DC-link voltage is maintained at constant level by the proposed controller with D-STATCOMAs a result of the RNN and CS algorithms, the DC-link voltage is maintained at a constant level. The proposed RNN and CS algorithms are used to keep the DC connection voltage stable. Similarly, in the evaluation of grid connected PV/WT with D-STATCOM based on hybrid RNN and CS algorithm, the voltage interruption and swell mitigation has been illustrated in Fig. 16 (a) and Fig. 17 (a). In order to confect the load voltage, D-STATCOM emits an injected voltage. The voltage swell occur over a period of seconds ranging from 0.05 to 0.12 secs. A complete loss of supply or load voltage is known as an interruption. To inject voltage into the mitigation process, the D-STATCOM is used. In Fig. 18 (a) show, If all these faulty and load variation apply on PCC of the system at different situation as given in Table 2 Then voltage sag, swell and interruption appeared in system so it will be strongly. Then the proposed controller with D-STATCOM mitigates the PQ issues and achieved stability for system. Transmission lines are typically used to deliver PV/WT/Battery source voltage and current to the nonlinear load. The proposed technique, which is based on the system's voltage and current, is used here to generate control pulses for the converter. The proposed method utilises the voltage and current values as input in an aesthetic way. When the procedures are completed, the hybrid RNN techniques are well-suited to generate the optimal D-STATCOM control pulses. Table 3 analyses and illustrates the implementation parameters.

The proposed method is used to achieve smooth DC-link power and PQ enhancement in a grid connected PV/WT/Battery hybrid system. The performance of the proposed controller is comparable to that of existing PI and ANN controllers. The proposed method's efficacy is analyzed using a comparison analysis the existing method is compared to voltage sags, voltage swell, and voltage interruption. Fig. 15 shows the results of the various comparison analysis (b). In comparison to other existing methods, the proposed approach has a high efficiency based on the analysis of the rising time and voltage level. Similarly, the voltage swell and voltage interruption are compared with the existing method in Fig. 16 (b), Fig. 17 (b) and Fig. 18 (b). The comparison analyses of the proposed method THD at various methods are illustrated in the Fig. 20 and Fig. 21. The suggested method's voltage and current magnitudes, as well as their waveforms, are analyzed using FFT analysis. In the PQ problem, the voltage signal is disrupted at specific time instants. Various approaches are used to measure and demonstrate the PQ impacted voltage variation. The Total Harmonic Distortion (THD) values are then obtained and compared to those calculated using the proposed method. THD values for device in proposed controller, ANN, and PI controller are 1.57 percent, 9.7 percent, and 12.88 percent, respectively, according to FFT analysis. The results of the analysis reveal that the proposed strategy significantly decreases the PQ problem, and their performance is assessed. THD values of unbalanced circumstances are also analyzed using FFT analysis with different controllers. Based on the facts, the proposed hybrid RNN with CS technique outperforms the competition in terms of PQ compensation. Under all disturbances, the DC link voltages are almost comparable to the reference value. The simulation results are separated into three different scenarios: voltage sag, voltage swell, and voltage distortion. In addition, the harmonics (THD ratio) are thoroughly examined in this result part. The proposed grid connected PV/WT/Battery system with D-STATCOM based hybrid RNN technique in this paper has the functions of enhancing PQ and assuring electricity supply continuity.Fig. 23 depicts the performance analysis of the battery energy storage system in this operational state. The discharge and charge of the battery to maintain power fluctuation can be seen with the help of the bidirectional current controller interlink with the hybrid controller, which is controlled by generated switch signals S_1 and S_2. Which is capable of maintaining the DC-bus voltage, allowing the charging current to properly regulate to compensate for power fluctuations. When a fault occurs between 0.42 and 0.5 seconds, the bus voltage drops suddenly, and the bus voltage drops below the reference voltage, resulting in the battery being discharged. When a three-phase load is applied, the duty cycle forces current from the DC bus to the battery for charging. Fig. 23 depicts the performance of the battery current and SOC waveforms.

5. Conclusion

For smoothing DC-link power and mitigating PQ difficulties, a hybrid PLL-based VSC controller and a hybrid RNN-based D-STATCOM with a CS algorithm are presented in this paper. The HPG system's controllers, such as the hybrid PLL-based VSC controller, D-STATCOM with hybrid method, and battery bidirectional controller, are all coordinated to maintain the system's stability and reliable. The suggested PLL-based controller is capable of operate the HPG system at maximum power. As a result, the DC link voltage is always kept at its nominal value. While the battery SOC management overcomes the intermittent problem by controlling the power injected into the utility grid. In the other proposed method, grid connected PV/WT/Battery hybrid system sideways parameters, load sideways constraints, and corresponding control signals for the D-STATCOM have been employed for training. The proposed RNN-CS-based controller generated control signals for the D-STATCOM based on voltage and current disturbances after training. Robustness, reliability, and flexibility to a wide range of issues are all advantages of the proposed control technique. The proposed approach has been implemented, and its performance under various types of source-side voltage fault situations has been analyzed.The performance of D-STATCOM must be improved in order to improve PQ. Voltage sags and swells to compensate for the voltage interruption, and system power quality is improved. The proposed method, ANN, and PI method have been employed for FFT analysis. the THD values are analysed in both the proposed and existing controllers. When compared to hybrid RNN-CS technique-based D-STATCOM controllers, the comparative results suggest that the proposed controller can enhance PV/WT/Battery system performance and improve PQ challenges.

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