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Adaptive Control Of Grid Integrated Photovoltaic Using Recurrent Neural Network

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Abstract: The Photovoltaic (PV) demand is increasing day by day globally. To meet the demand PV is generally connected to the distribution grid. To achieve higher efficiency of the PV integrated distribution grid, this paper proposes an algorithm named Recurrent Neural Network (RNN) for the control of the PV integrated distribution grid system. This algorithm controls the Voltage source converter (VSC) by aiming for harmonic mitigation, load balancing and other power quality problems. This algorithm focuses to deliver maximum power on the grid side VSC. The proposed technique is designed and simulated in a MATLAB environment using SIMULINK. The results confirm that the Total Harmonic Distortion is reduced as recommended by the IEEE-519 standard.

Keywords*—Power Quality, Total Harmonic Distortion (THD), Distribution Grid Synchronization, PV integration, RNN;*

1. Introduction

Renewable energy is a vital alternative source to meet the domestic and commercial load demand owing to the fast depletion of conventional sources [1]. Recently, PV energy sources is favored among all available renewable energy because of their easy availability, easy installation and eco-friendly. It is prevalent to develop microgrids integrating the distribution grid with PV systems to meet the demands. An efficient voltage source converter (VSC) is required to couple the PV system and distribution grid[2]. For active PV systems and distribution grid synchronization, a precise and fast algorithm is required to estimate the fundamental components of the Point of common coupling (PCC) considering the power quality instabilities. MPPT (maximum power point tracking) is used in the PV system as a control technique to extract more power from the PV panel. Based on the variation of the duty ratio of the switches used in the DC-DC converter MPPT is achieved[3].

Power quality is a major issue due to the larger use of nonlinear loads and the existence of high inductive loads on the utility side. The utility nonlinear load produces distortion in the power grid current followed by the distortion in the grid voltage. There is an additional burden in the grid due to the drawing power at a lower factor in heavy utility load. Also, an unbalancing in current in the network may lead to a heavy return current on the neutral line [4]. The synchronization of the PV system with the distribution grid includes various power converter stages which result in power quality issues. Hence, a special focus is required to mitigate the power quality issues in addition to the feeding of power to the grid from the PV system. To overcome the power quality issues a shunt active compensator is used for load compensation[5]. It is expected to mitigate the power quality issues using VSC which will be cost-effective and attractive[6].

Researchers have proposed various techniques such as quadratic regulator[7], Widrow-Hoff algorithm[8], and hybrid controller[9] and further various techniques have been proposed. Furthermore, many researchers have focused on three-phase power systems compared to single-phase power systems[10]. A detailed reactive power compensation with a specific operation goal is proposed with a dynamic control scheme[11]. Control techniques to cancel harmonic functions on the inverter side have been proposed[12], [13]. Voltage and current control methods are used, in addition, an extended reference signal was proposed using ANFIS for gate signal generation[14]. Other control techniques such as prompt symmetrical components theory[15] and subsidiary current control using a hysteresis controller[16] are also proposed. Control techniques based on adaptive theory are also notable techniques in power quality improvement[17]–[21]. From the literature, it is observed that there is still a need for the development of steady-state and dynamic performance with an optimal control technique.

This paper proposes an RNN-based VSC controller in combination with the MPPT on the PV system. The distorted current and voltage are fundamentally extracted with weighted functions for generating gate signals for VSC. This paper contributes to the development of a robust

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and efficient algorithm for PV-connected distribution grids. The proposed technique is simulated in a MATLAB environment and validated according to IEEE 519 standards.

2. System Description

The Proposed system includes a three-phase distribution grid integrated with a PV system coupled with the non-linear load using PCC (Point of common coupling). The detailed schematic view of the proposed method is presented in Fig. 1. A Passive filter is used to integrate the grid and PV system. STATCOM is used to improve the voltage stability of the power system. Luo Converter and VSI (Voltage Source Inverter) are used to integrate the PV system and distribution grid. Harmonics and other power quality issues are produced due to nonlinear load and it is mitigated using an LCL filter. On the PV side, MPPT (Maximum Power Point Tracking) is ensured using an algorithm while it is synchronized on the grid side. A Recurrent Neural Network (RNN) technique is used to generate the reference current, to eliminate the harmonics for any change in the source and load voltage. Additionally, pulses for VSI are created by the hysteresis current controller in the way injective reactive power compensation and eliminate harmonics.

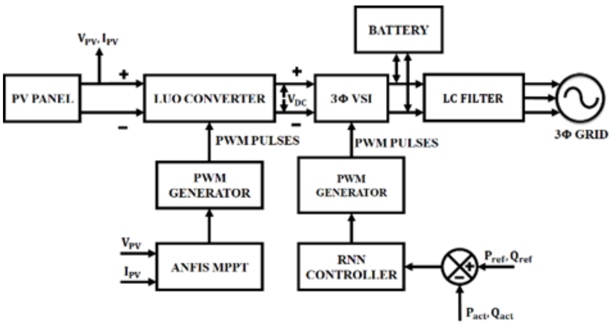

Fig.1. Schematic View of the Proposed method

3. System and Methodologies

A. Harmonic fundamental asesment

The assessment of harmonic fundamental components is subjected to the control technique. Hence the following empirical relations are a key role in designing the proposed method. The universal equation of the current value on the load side of the distribution system is expressed in Equation (1). This equation includes the fundamental equation and k[th] harmonic. Equation (1) is rewritten as Equation (2)

$$\mathrm{i_L}\ (t) = \sum_{k=1}^{N} \mathrm{I_{Lk}}\ \sin(\mathrm{k\omega t} + \emptyset_\mathrm{k} \qquad (1)$$

$$\mathrm{i_L}\ (t) = \sum_{k=1}^{N} \mathrm{A_k} \sin(\mathrm{k\omega t}) + \mathrm{B_k} \cos(\mathrm{k\omega t}) \quad (2)$$

$$I_{Lk} = \sqrt{A_k^2 + B_k^2} \quad \text{and} \quad \theta_k = \tan^{-1}(B_k / A_k) \quad (3)$$

Everywhere $\mathrm{A_k} = I_{Lk} \cos\theta_k$

$\mathrm{B_k} = I_{Lk}\ \sin\theta_k$

The magnitude and phase of the kth harmonic are calculated as Equation (3). In this work, the dynamic load current corresponding to different harmonics is measured using RNN. This algorithm helps to reduce the error between the desired value and the actual value. Equation (4) is applied to measure the error value. The detailed expression can be referred to from [18].

$$e(t) = \sum_{k=1}^{N} \mathrm{A_k} \sin(\mathrm{k\omega t}) + \mathrm{B_k} \cos(\mathrm{k\omega t}) - \mathrm{i_{Lk}}\ (\mathrm{t}) \quad (4)$$

B. PV system

PV system has solar cells made of semiconductor and produces voltage due to exposure to solar irradiance. Based on the various level of photon irradiance and level of energy voltage is produced in the p-n junction. The band gap energy is very important in deciding the solar PV system output voltage.

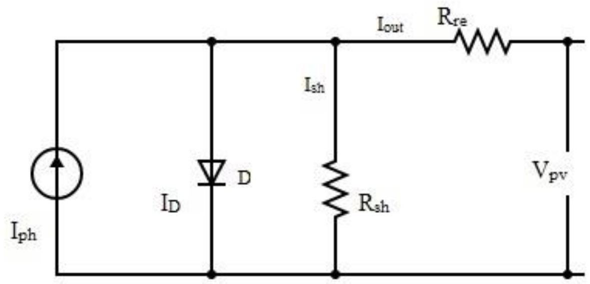

Fig.2 PV system equivalent circuit

$$I_{out} = I_{ph} - I_{out} \left[exp \frac{V_{out} + I_{out} * R_s}{V_{ph}} \right] - 1] - \left[\frac{V_{out}+I_{out}*R_s}{R_{re}}\right] \quad (5)$$

Fig.2 shows the PV system equivalent circuit which generally consists of a diode offering better transactions amid accuracy and simplicity. The I_{ph} is based on solar radiation and temperature. In the modeling of the PV system, the voltage on the input and source sides is evaluated using Equation (5).

C. PV system converter

Luo converter topology is used in this proposed system. It has a series of DC-DC boost converters. The voltage lift technique is used in this topology. This topology helps to achieve high power density with a simple structure. It has two diodes, two capacitors, one switch, and one inductor. Other supplement switches are used to achieve inversion mode. The Luo converter topology is shown in Fig.3.

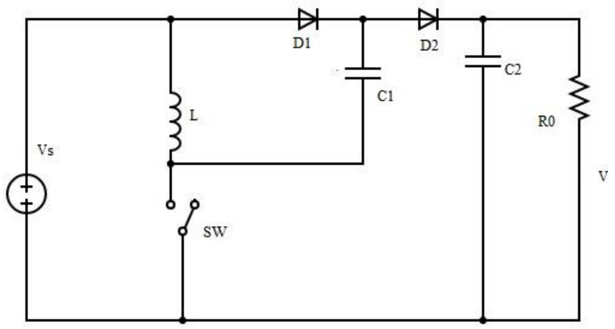

Fig.3 Schematic of Luo Converter topology

Recently voltage lift technique is widely used in PV systems. This converter converts the positive voltage into positive voltage. It operates in the first quadrant with higher voltage magnification. In the simulation, all the parameters are assumed as ideal. It operates in continuous mode to attain high power density. There are two modes depending on the duty ratio for this topology. Mode1 is when the switch is ON state. Here D1 conducts and C1 charges. The current stored in the inductor depends on the level of input voltage. The other capacitor C2 provides energy to load. On other hand, Mode2 is when the switch is in the OFF state. Here D2 starts to conduct and c2 delivers energy to the load by reducing the inductor current. Finally, the inductor current reduces to state (Vo-2Vs).

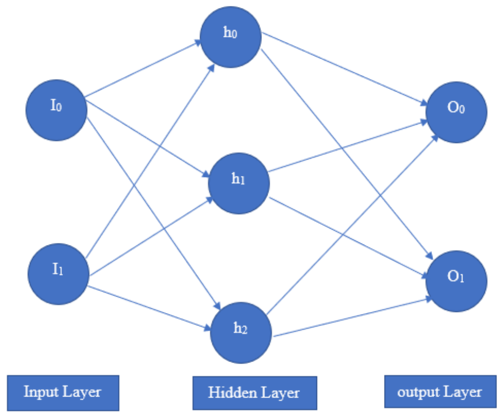

Fig.4 Schematic structure of RNN

D. Generation of Position current using RNN

The disturbance in voltage and current is caused owing to the large demand needs of the nonlinear load. Though, we have several mitigation techniques to improve the power quality. One of the finest methods is the inoculation of conflicting harmonics in PCC. To achieve this accurate position or reference current is necessary. RNN is proposed in this work to generate pulses of VSI to improve the power quality. The DQ method is used to extract the acual parameters from the grid. The schematic structure of RNN is shown in Fig.4.

RNN looks like an Elamn network where it has an input, output and hidden layer. The output of the hidden layer at (k-1) is considered as the added input for each step of k. A supplementary memory is required to clutch the dynamic behavior of the complete system. This system gathers the dynamic behavior from system feedback and later compares it. The weights of the RNN hidden layers are instantly upgraded by the back-propagation method.

The harmonic components of the system are derived from the load current, whereas Equation (6) gives the empirical relationship between the load current and the harmonic component. The required pulses are generated by the RNN to eliminate the Harmonics.

$$I_h = I_L - I_{base} \quad (6)$$

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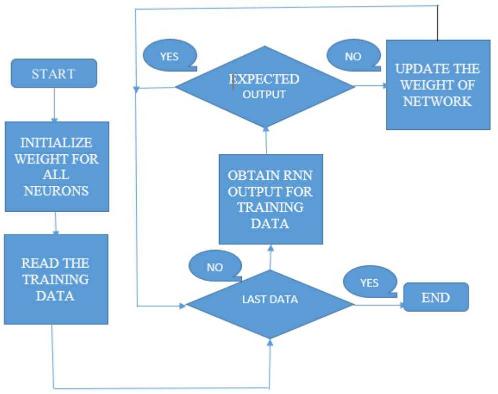

Fig.5 Flow chart of RNN Training

RNN consists of different hidden layers, where all layers are mapped equally with weights to obtain the desired output This network can capture the related data from the sequence. It operates with an arbitrary length for the complete sequence. RNN determines the relationship between the samples with the help of the input sequence. This algorithm is a time series state solution based on the error signals. It consists of a back propagation feedback system. The weight of the hidden layer calculation and the updating are completed in percentage to the incline error regarding the weight. In the case of the disappearing scenario the incline error and its weight outcome in a very minimal number which leads to a loss of information. In such cases, LSTM (Long Short Term Memory) is aided by RNN to solve this issue of loss of information. The main concept is holding long-term dependencies for a short duration. Here the delay cells are made to hold the data. This algorithm helps in mitigating harmonics and improves voltage stability. The one-to-one system is designed with forget layer, an input layer, an output layer, state layer concerning the gate. Here, the input and forget a layer of the gate controls the previous hidden state that contributes to the current state. The sigmoid function is used for scaling the layers of the network. Fig.5 shows the flow chart of RNN training.

4. Simulation Results and Discussions

The proposed method is simulated in MATLAB/Simulink platform. The analysis of the PV integrated grid system using STATCOM for eliminating harmonics and improving voltage stability is validated. The Luo converter is used for enhancing the PV system output voltage. The DC-link stability and overall current control are done with RNN.

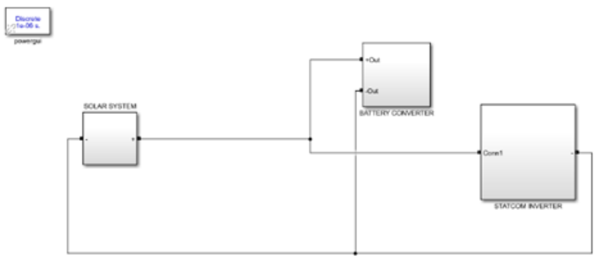

Fig.6 Grid Integrated PV system complete simulation block

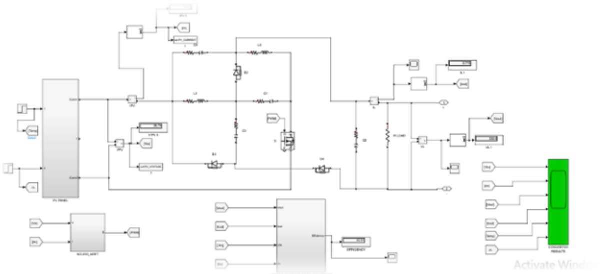

Fig.7 Grid Integrated PV system - solar and its converter

The overall blocks of the simulation of the proposed system are shown in Fig. 6. The solar and converter block of the proposed simulation is shown in Fig. 7. The battery and its converter block are shown in Fig.8. The STATCOM inverter block is shown Fig. 9.

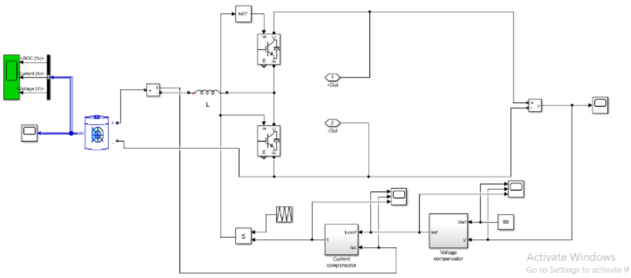

Fig.8 Grid Integrated PV system - Battery and converter block

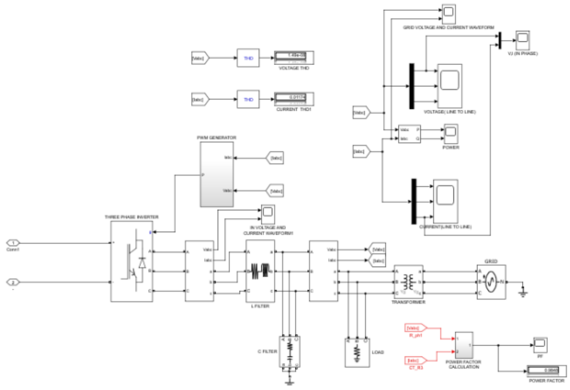

Fig.9 Grid Integrated PV system - STATCOM Inverter block

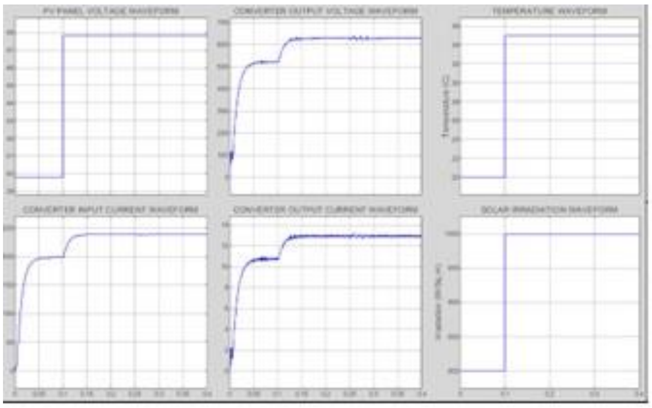

Fig.10 Output of PV system and Luo converter

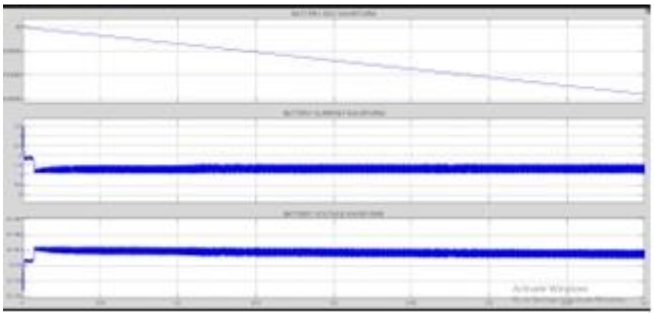

Fig.11 Output across the DC link

Fig.10 shows the output power from the PV system and across the converter. The maximum power generated can be observed which is fed to the next level. Fig 11 indicates the output obtained across the DC link. Fig .12 shows the voltage and current waveform on the grid side. Fig 13 shows real and reactive power waveforms. Fig.14 shows the load side current and voltage waveform. Fig. 15 shows the power factor waveform. Table 1 shows the comparison of settling time and RNN

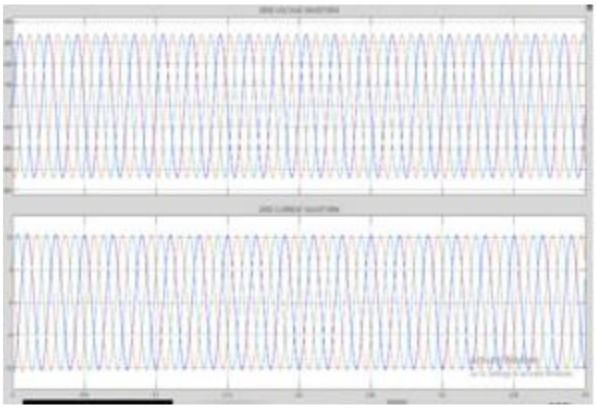

Fig.12 Voltage and Current waveform on the grid side

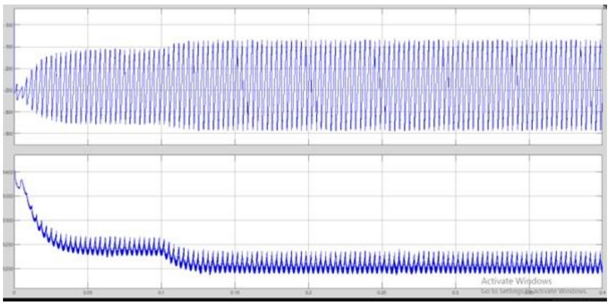

Fig.13 Real and Reactive power waveform

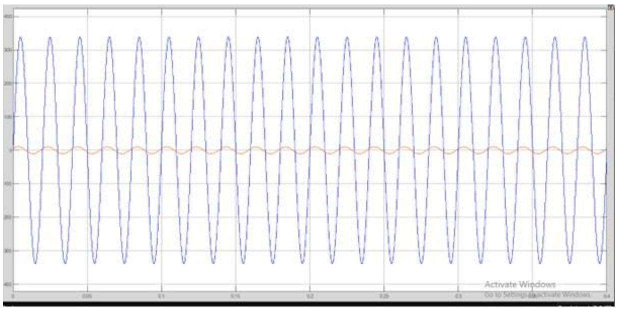

Fig.14 Laod side current and voltage waveform

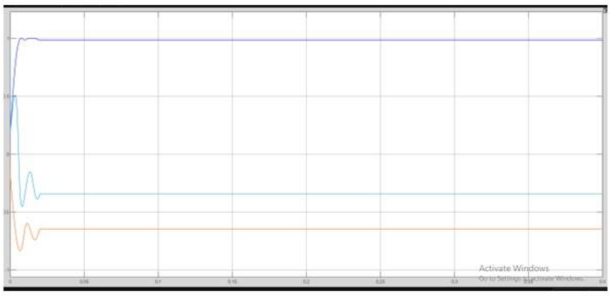

Fig.15 Power factor waveform

Table 1 Comparison of THD and settling time

Parameters	PI	DQ	RNN
Settling Time	3.0	2.5	1.65
THD	4.6%	4.1%	2.5%

5. Conclusion

In this work, RNN based control technique is proposed for the distribution grid integrated PV system power quality improvement.

The following are the viewpoints of the proposed method.

1. The proposed technique helps to inject active and reactive power for all different separation levels.
2. As per the IEEE standard, the THD is less than 5%.
3. Unity power factor operation is targeted by maintaining the reactive power at zero.
4. RNN provides adjustable system voltage regulation.
5. A fast reliable grid-integrated PV system is ensured.

The RNN control applies to several atypical nonlinear loads at the Point of common coupling. This algorithm provides a simplistic execution based on its design and control techniques. It is observed this algorithm feeds the nonlinear load at PCC and similarly handovers surplus power to the distribution grid. Throughout voltage sags, RNN helps to support voltage via inoculating a specific amount of reactive power to lift the voltage adhering to voltage operational limits. STATCOM helps in delivering power in the absence of sunlight and maximum utilization of the RNN system is observed. All performance is validated through simulation in MATLAB environment. Abnormal environmental conditions such as solar irradiation, unbalanced load, voltage sags, swells, and distorted grid conditions are put through to validate the system. On all abnormal conditions, the THD of the grid current is found to be within limits adhering to IEEE-519 standards.

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