FUZZY With DNLMS Control Algorithm Based Grid-Integrated Solar PV System For Performance Improvement

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Abstract—An integration of renewable sources based distributed generating systems encounters various power quality issues due to uncertain loads at the distribution end. These uncertainties arise due to nonlinearity, disturbances or unbalanced loads. A three-phase grid-integrated solar photovoltaic (PV) system incorporating a control technique based on a modified decorrelation normalized least mean square (DNLMS) algorithm with fuzzy, aiming to enhance its overall performance under adverse conditions, is presented in this work. The three-phase, grid-tied, single-stage solar PV system comprises a solar PV array with a suitable maximum power point tracking method, filters, loads, and a capacitor fed voltage source converter (VSC). The key objective of the solar PV integrated structure with an adaptive law based control algorithm is to attain a unity power factor (UPF) at the grid end ensuring harmonics mitigation from the grid currents. Moreover, this structure effectively transfers active power from the PV array to the local loads and the grid. These aforesaid objectives are achieved through providing controlled switching pulses to the insulated gate bipolar transistor based VSC using the modified DNLMS control algorithm, fuzzy with fast convergence rate. Harmonics-free, sinusoidal reference grid currents, are obtained by using the modified DNLMS algorithm. A simulation model developed in MATLAB/Simulink is used for the validation of the modified DNLMS-based control approach. In the laboratory, an experimental prototype is developed and the proposed algorithm is implemented to verify its performance.

Index Terms—Decorrelation normalized least mean square (DNLMS) algorithm, maximum power point tracking (MPPT) technique, photovoltaic (PV) array, power quality (PQ), total harmonics distortion (THD).

I.INTRODUCTION

The warming as a result of climate change, has been established beyond doubt. In fact, the fossil fuel based energy sources emitting greenhouse gases, are the lead cause of the effect. Coordinated global effort under the aegis of the United Nations framework convention on climate change (UNFCCC), is being attempted to contain the rise of global atmospheric temperature below 2 °C of preindustrial level, which are to be reflected in the intended nationally determined contributions of each country under the UNFCCC framework. This underscores the centrality of renewable energy sources as a dominant alternative to the fossil fuel based sources of electrical power generation, especially when electrical energy is being envisaged to replace petroleum as energy sources for vehicles, which are among the major sources of environmental pollutants. While renewable energy includes many existing and evolving resources in its fold, solar power leads the pack currently.

The extensive research and development work have been done on the technology making it commercially more competitive. Power engineers exhibiting interest toward the development of advanced information technologies in this field by modeling, designing, and implementing novel techniques. An extensive literature work has been reported to model solar photovoltaic (PV) array [1] and for harnessing its peak power [2], [3]. Among the peak power extraction techniques, perturb and observe (P&O), incremental conductance, variable step size incremental resistance, digital lock in amplifier, fuzzy logic method, Grey wolf optimization, particle swarm optimization, sliding mode controller, etc., are some adopted conventional methods. Integration of renewable sources based energy generating systems (RSEGS) into the national grid at the point of interconnection (POI), is performed through solid-state devices based power converters such as voltage source converters (VSCs), buck and boost converters. Double-stage and single-stage systems are the most common arrangements adopted to integrate the PV array with the national grid. A boost converter responsible for peak solar power tracking, is incorporated between the PV array and VSC, executing power conversion in two stages. In the contrary, the boost converter is absent in the later one [4] performing single stage of power conversion. By mounting the solar PV array at the distribution end, provides alleviated burden on the conventional grid at the POI by meeting energy demand of the customer at higher level of satisfaction. However, an integration of RSEGS encounters challenging issues due to uncertainties in the distribution system [5]. These uncertainties arise due to nonlinearity, disturbances or unbalanced loads. Moreover, grid-tied RSEGS come across challenges in maintaining reliability, stability, synchronization, and performance of the overall system. Hence, the grid-tied RSEGS have to satisfy the restrictions imposed by the grid codes [6], [7].

Grid-tied distributed generators suffer from various power quality issues at the load as well as grid side [8]. Hence, it is mandatory to maintain the reliability, stability, and quality of energy supplied to the utility. The aforementioned issues are addressed in the literature and further improvement in these techniques have been going on [9] to enhance the system dynamic performance. Many adaptive techniques such as as least mean fourth (LMF) [9], direct power control [10], discrete Fourier transform, droop control [11], decorrelation normalized least mean square (DNLMS) [12], modified variable step size least mean square (LMS) [13], dual-tree complex wavelet transform [14], phase-locked loop (PLL) technique, etc., have been reported in the literature that can be used to control, compute phase and amplitude of signals ensuring harmonics elimination and improved performance of the grid-integrated distribution system. Moreover, various filters and observer structures have been proposed for harmonics and fundamental extraction. Some of them are adaptive vectorial filter, Kaman filter, decomposition based wavelet filters, concise discrete adaptive filter, Wiener filter, frequency adaptive observer etc. Estimation of weight parameters in many fields such as signal processing and power system applying adaptive controller, has become a key area of research owing to the merits of the method. Simplicity of computation has encouraged the use of simple LMS by researchers. In LMS, the squared error is taken as the cost function. Further enhancement has been made in the LMS technique such as normalized LMS (NLMS), LMF, adaptive LMS, Filter-X LMS, and quantized kernel least mean square. Some publications have proposed DNLMS where the error is calculated by considering a decorrelation operator (DO). Minimizing l2 norm of the decorrelated posteriori error (DPE) with a DO, contributes equations of the DNLMS-based control algorithm, thus resulting in fast convergence rate and good performance.

This thesis deals with a modified DNLMS-based control algorithm for a single-stage solar PV system integrated into the national grid. The modified DNLMS algorithm is used to estimate the active weight component of the load current, which is used to generate the reference grid currents. A DO is taken for the improvement of the filter performance. This filter works through the estimation of weight component of the input signal. This filter depends on the weight updating law, which depends on a step size. A proper step size has to be chosen for fast convergence and accurate results. Here, the step size has the advanced proficiency to regulate itself to fulfill the need, thereby proving its behavior under steady as well as dynamic conditions. Hence, the estimated weight has the capability to tune itself according to the requirement. Stability of the algorithm is analyzed through the convergence of weight deviation vector in the sense of mean square error. Moreover, dynamic behavior of the system is studied under sudden change in the unknown system. Main objectives of the proposed system are as follows.

1) Estimation of the active and reactive fundamental weights of the load current is done by using the modified DNLMS algorithm. Necessity of the PLL is avoided by unit template estimation from the grid voltage.

2) Power factor correction (PFC), grid currents balancing, and reduced total harmonic distortion (THD) at the grid side parameters at nonlinear load under steady-state and dynamic conditions.

3) Capability of meeting peak solar power at different solar irradiation.

4) This structure effectively transfers active power from the solar PV array with P&O-based MPPT technique, to the local loads as well as the grid. The grid-tied solar PV system, including the proposed modified DNLMS-based control is simulated at nonlinear load under various dynamic conditions describing its working and system performance. A comparative study on the performance of the modified DNLMS algorithm with conventional algorithms, is presented to study the superiority of the given logic. A Simulation results of the three-phase grid-integrated PV system incorporating the P&O-based MPPT technique and the modified DNLMS algorithm, is developed. Further, its behavior under dynamic conditions is demonstrated through test results.

II.LITERATURE SURVEY

Modeling and circuit-based simulation of photovoltaic arrays

This presents an easy and accurate method of modeling photovoltaic arrays. The method is used to obtain the parameters of the array model using information from the datasheet. The photovoltaic array model can be simulated with any circuit simulator. The equations of the model are presented in details and the model is validated with experimental data. Finally, simulation examples are presented. This paper is useful for power electronics designers and researchers who need an effective and straightforward way to model and simulate photovoltaic arrays.

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A single-stage three-phase grid-connected photovoltaic system with modified MPPT method and reactive power compensation

Single-stage grid-connected photovoltaic (PV) systems have advantages such as simple topology, high efficiency, etc. However, since all the control objectives such as the maximum power point tracking (MPPT), synchronization with the utility voltage, and harmonics reduction for output current need to be considered simultaneously, the complexity of the control scheme is much increased. This paper presents the implementation of a single-stage three-phase grid-connected PV system. In addition to realize the aforementioned control objectives, the proposed control can also remarkably improve the stability of the MPPT method with a modified incremental conductance MPPT method. The reactive power compensation for local load is also realized, so as to alleviate grid burden. A DSP is employed to implement the proposed MPPT controller and reactive power compensation unit. Simulation and experimental results show the high stability and high efficiency of this single-stage three-phase grid-connected PV system.

III.PHOTOVOLTAIC INVERTER

A PV cell is a simple p-n junction diode that converts the irradiation into electricity. Fig.1 illustrates a simple equivalent circuit diagram of a PV cell. This model consists of a current source which represents the generated current from PV cell, a diode in parallel with the current source, a shunt resistance, and a series resistance.

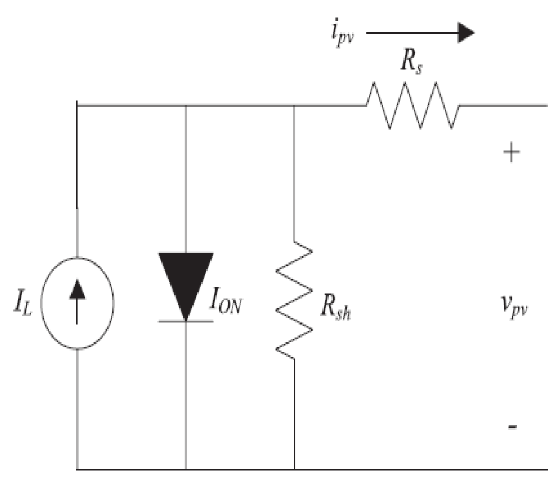

Fig.1 Equivalent circuit diagram of the PV cell

HARMONICS

The typical definition for a harmonic is "a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency.". Some references refer to "clean" or "pure" power as those without any harmonics. But such clean waveforms typically only exist in a laboratory. Harmonics have been around for a long time and will continue to do so. In fact, musicians have been aware of such since the invention of the first string or woodwind instrument. Harmonics (called "overtones" in music) are responsible for what makes a trumpet sound like a trumpet, and a clarinet like a clarinet.

Electrical generators try to produce electric power where the voltage waveform has only one frequency associated with it, the fundamental frequency. In the North America, this frequency is 60 Hz, or cycles per second. In European countries and other parts of the world, this frequency is usually 50 Hz. Aircraft often uses 400 Hz as the fundamental frequency. At 60 Hz, this means that sixty times a second, the voltage waveform increases to a maximum positive value, then decreases to zero, further decreasing to a maximum negative value, and then back to zero. The rate at which these changes occur is the trigometric function called a sine wave, as shown in figure 1. This function occurs in many natural phenomena, such as the speed of a pendulum as it swings back and forth, or the way a string on a voilin vibrates when plucked.

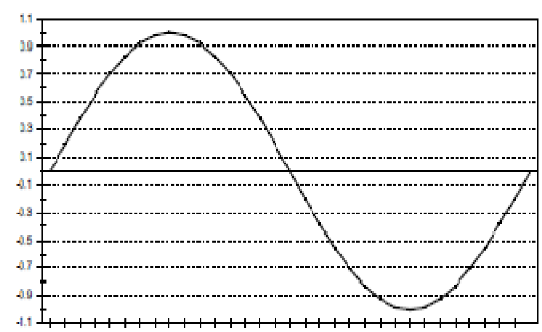

Fig2. Sine wave

IV.FUZZY

In recent years, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision support systems, and portfolio selection. To understand why use of fuzzy logic has grown, you must first understand what is meant by fuzzy logic.

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Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalve logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with un sharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of FL. Even in its more narrow definition, fuzzy logic differs both in concept and substance from traditional multivalve logical systems.

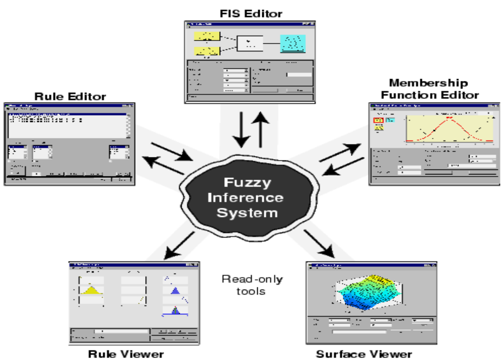

Fig.3 The primary GUI tools of the fuzzy logic toolbox

V.PROJECT DESCRIPTION AND CONTROL DESIGN

MODIFIED DNLMS ALGORITHM

The modified DNLMS algorithm is an advanced version of the basic DNLMS algorithm with improved performance, stability, and robustness in its behavior. In the modified DNLMS algorithm, the step size of the weight equation adjusts itself to have improved performance. Fig. 1 shows the schematic of adaptive filter based system identification and weight estimation structure of the modified DNLMS algorithm. Here, ϕopt is the set of unknown weights and ϕ is the set of estimated weight. The input signal (x(r)) for rth sample time is expressed as

$$x(r) = \varphi^T u(r) + \eta(r) \tag{1}$$

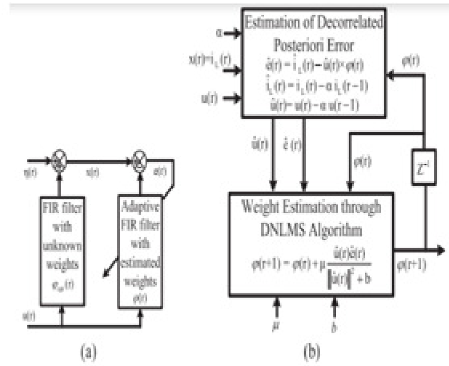

Fig4: Diagram of adaptive filter based system identification and weight estimation system

where η(r) and ϕ are the noise and weight parameters, respectively. The error between the desired and the actual signals, decorrelated output error and decorrelated posteriori error after introducing the DO (α), are estimated as [26].

$$e(r) = x(r) - \varphi^T(r)u(r) \tag{2}$$

$$\hat{e}(r) = \hat{x}(r) - \varphi^T(r)\hat{u}(r) \tag{3}$$

$$\hat{e}_p(r) = \hat{x}(r) - \varphi^T(r+1)\hat{u}(r) \tag{4}$$

where uˆ(r) and xˆ(r) are the signals after the introduction of "α" into the formulation and are expressed as [26]

$$\hat{x}(r) = x(r) - \alpha x(r-1) \tag{5}$$

$$\hat{u}(r) = u(r) - \alpha u(r-1). \tag{6}$$

Hence, the error can also be written as

$$\hat{e}(r) = \left(x(r) - \varphi^T(r)u(r)\right) - \alpha\left(x(r-1) - \varphi^T(r)u(r-1)\right) \quad (7)$$

where $\varphi(r)$ is the weight parameter associated with the adaptive law, derived from the cost function defined as

$$\min_{\varphi(r+1)} \hat{e}_p(r) = \left(\hat{x}(r) - \varphi^T(r+1)\hat{u}(r)\right)^2. \quad (8)$$

Such that

$$\|\varphi(r+1) - \varphi(r)\|_2^2 \leq \delta. \quad (9)$$

Depending upon its robust behavior, the weight at each sample time is updated using the adaptive law

$$\varphi(r+1) = \varphi(r) + \mu' \frac{\hat{u}(r)\operatorname{sign}\hat{e}(r)}{\|\hat{u}(r)\|_2 + b} \quad (10)$$

where μ is the step size responsible for adjusting the weight in the adaptive law such as

$$\mu' = \min\left(\sqrt{\delta(r)}, \mu\frac{|\hat{e}(r)|}{\|\hat{u}(r)\|_2}\right). \quad (11)$$

$$\varphi(r+1) = \varphi(r) + \mu\frac{\hat{u}(r)\hat{e}(r)}{\|\hat{u}(r)\|_2^2 + b} \quad \text{or}$$

$$\varphi(r+1) = \varphi(r) + \min\left(\sqrt{\delta}, \mu\frac{|\hat{e}(r)|}{\|\hat{u}(r)\|_2}\right)\frac{\hat{u}(r)\operatorname{sign}\hat{e}(r)}{\|\hat{u}(r)\|_2 + b}. \quad (12)$$

For stability analysis, a delta sequence is chosen as

$$\delta(r+1) = \theta\delta(r) + (1-\theta)\|\varphi(r+1) - \varphi(r)\|_2^2$$
$$= \theta\delta(r) + (1-\theta)\min\left(\mu^2\frac{|\hat{e}(r)|^2}{\|\hat{u}(r)\|_2^2}, \delta(r)\right) \quad (13)$$

where the forgetting factor (θ) is chosen with the operating range of 0 <θ< 1.

Stability Analysis

From (12) and (13), the weight equation is modified as

$$\varphi(r+1) = \varphi(r) + \sqrt{\frac{\delta(r+1) - \theta\delta(r)}{(1-\theta)}}\frac{\hat{u}(r)\operatorname{sign}\hat{e}(r)}{\|\hat{u}(r)\|_2}. \quad (14)$$

Let the error between ϕopt and ϕ is denoted as ϑ. Hence

$$\vartheta(r) = \varphi_{\text{opt}} - \varphi(r). \quad (15)$$

The deviation vector of weight parameter (ϑ (r + 1)) is given as

$$\vartheta(r+1) = \vartheta(r) - \sqrt{\frac{\delta(r+1) - \theta\delta(r)}{(1-\theta)}}\frac{\hat{u}(r)\operatorname{sign}\hat{e}(r)}{\|\hat{u}(r)\|_2}. \quad (16)$$

Multiplication of $\vartheta^T(r+1)$ to (16) yields

$$\vartheta(r+1)\vartheta^T(r+1) = \vartheta(r)\vartheta^T(r) - \sqrt{\frac{\delta(r+1) - \theta\delta(r)}{(1-\theta)}}\left(\frac{\hat{u}(r)\vartheta^T(r)\operatorname{sign}\hat{e}(r)}{\|\hat{u}(r)\|_2} + \frac{\vartheta(r)\hat{u}^T(r)\operatorname{sign}\hat{e}(r)}{\|\hat{u}(r)\|_2}\right) + \frac{\delta(r+1) - \theta\delta(r)}{(1-\theta)}\frac{\hat{u}(r)\hat{u}^T(r)}{\|\hat{u}(r)\|_2^2}. \quad (17)$$

The expectation of (17) gives

$$E\left\{\vartheta(r+1)\vartheta^T(r+1)\right\} = E\left\{\vartheta(r)\vartheta^T(r)\right\} - E\left\{\sqrt{\frac{\delta(r+1) - \theta\delta(r)}{(1-\theta)}} \times \left(\frac{\hat{u}(r)\vartheta^T(r)\operatorname{sign}\hat{e}(r)}{\|\hat{u}(r)\|_2} + \frac{\vartheta(r)\hat{u}^T(r)\operatorname{sign}\hat{e}(r)}{\|\hat{u}(r)\|_2}\right)\right\} + E\left\{\frac{\delta(r+1) - \theta\delta(r)}{(1-\theta)}\frac{\hat{u}(r)\hat{u}^T(r)}{\|\hat{u}(r)\|_2^2}\right\}. \quad (18)$$

When the system reaches steady state (i.e., $r \to \infty$), one can write

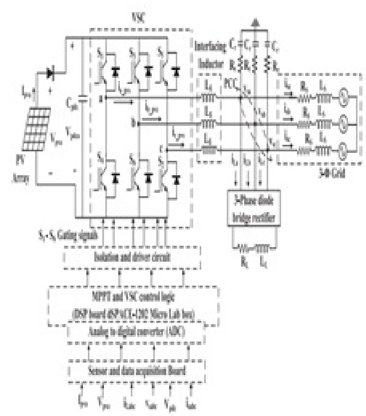

Fig5: Proposed diagram

SOLAR PV SYSTEM WITH P&O MPPT TECHNIQUE AND A MODIFIED DNLMS-BASED CONTROL ALGORITHM

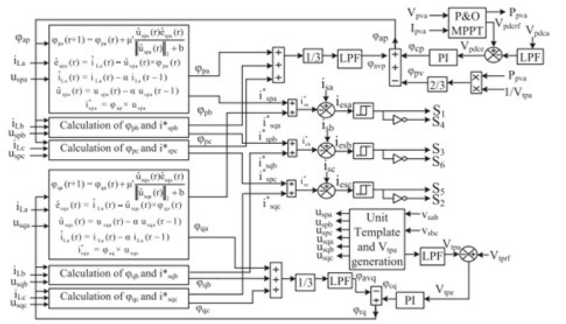

Fig6: DNS algorithm structure

Fig. 5 depicts the schematic of a solar PV system consisting of a solar PV array, integrated into the grid at POI through a VSC and interfacing inductors (Lf i) feeding power to a load of nonlinear nature. Lf i gives advantage of grid current ripples mitigation. Moreover, the mitigation of switching ripples at the POI is accomplished using an RCfilter. Single-stage power conversion is achieved through the dc-link capacitor (Cpdc) associated with the VSC. An uncontrolled diode bridge rectifier together with RL load is taken to realize a nonlinear load. An extensive simulation work is carried out using MATLAB/Simulink model under possible dynamic conditions considering the load as nonlinear. Verification of the control scheme is done by assembling a laboratory prototype. Fig. 6 illustrates the control logics used for the system. Two control methodologies are involved in the PV system operating at the grid-integrated mode. P&O MPPT scheme helps in achieving the goal of maximum PV power extraction through estimating the reference voltage required at dc link (Vpdcrf), which is to be maintained at desired value. The power loss in the dc link is also included in the control scheme with the modified DNLMS algorithm that estimates the load active and reactive components. A feed-forward term is included in the control scheme to improve the system performance under dynamic conditions. The reference current of the grid depends upon the resultant weight component. It is made sure to obtain a harmonics-free reference grid currents synchronized with the grid voltages without the help of any PLL. The modified DNLMS based control logic is used to estimate the load active and reactive weights. The system is operated in the PFC mode.

Hence, the estimated active weight components of load currents are taken into account. The amplitude of current flow of the system is controlled through these estimated weights that result in control over the active power flow from the PV array to the grid, after meeting the local load power demand. Moreover, the PV system with the proposed modified DNLMS based control is capable of addressing unbalanced load, grid currents harmonics, and power factor. Further, the stability analysis of the system is done by considering the stability of dc-link voltage. For achieving satisfactory injection of active power into the grid, it is required to accomplish regulated dc-link voltage. This objective is achieved by using a PI controller as shown in Fig. 6, which takes the difference between Vpdcrf and voltage sensed at Cpdc (Vpdca).

VI.SIMULATION RESULTS

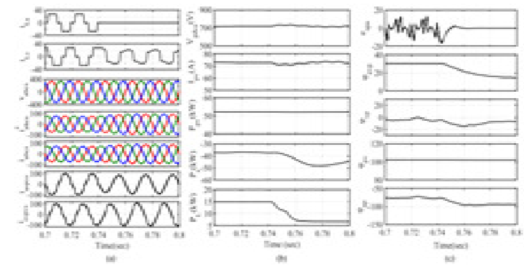

Fig7: simulation results of dynamic load condition

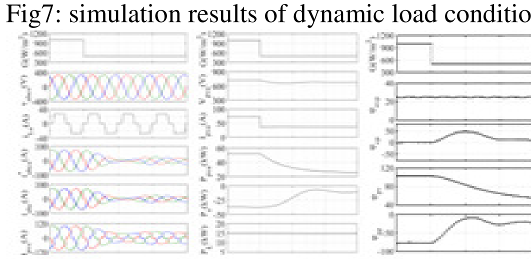

Fig8: Simulation results under variable solar insolation. sequence (δ(r)), and the forgetting factor (θ).

Hence, the step size is updated after each sampling instant. This value adjusts itself according to the knowledge of present and previous weights. For analysis point of view, the unit templates (u(r)) are considered as 1

For large step size (μ= 0.5), the right-side pole is with smaller magnitude and for small step size (μ= 0.5), the pole is with higher magnitude (nearer to the unit circle). Thus, for a large step size, the dynamic response is faster and for a small step size, the steady-state response is better. In this algorithm, the step size is initially (when error is high) a large value for fast dynamics and then reduces to a small value for accurate weight estimation. Here, μ= 0.5 is chosen to show its response with a large value and μ= 0.5 is chosen to show the response with a small value

VII.CONCLUSION

The proposed modified DNLMS algorithm with fuzzy at nonlinear load under various dynamic conditions has been demonstrated though the simulation results. The validation of the proposed modified DNLMS based control structure has been performed on a developed prototype. The prototype has been tested under possible dynamic conditions to prove its efficiency. A modified DNLMS based control has been adopted for active load weight estimation. P&O MPPT algorithm has been used for maximum solar power extraction through the estimation of reference dclink voltage that has to be tracked by the actual value. The need of PLL has been eliminated through the weight estimation with a guarantee of synchronization of the grid currents with the grid voltages. The grid current THD has been observed as 3.4% fulfilling the requirement according to the IEEE-519 standard. Active power flow has been observed from the test results. A satisfying performance has been recorded under dynamic conditions by achieving the steady-state condition at fast convergence rate with the proposed modified DNLMS control algorithm. UPF has been achieved at the grid side even when the load is nonlinear in nature.

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