Performance Improvement of Grid Connected Photovoltaic Power Generation System Using Robust Power Balanced Control (RPBC) Technique with Active Power Line Conditioning

M. Hariprabhu, K. Sundararaju

Abstract--- ***This work displays a grid-connected photovoltaic (PV) framework given a global maximum power point tracking (MPPT) system, which is performed by methods for the Robust Power Balanced Control (RPBC) strategy. The RPBC based MPPT method is utilized to tackle issues identified with mismatching marvels, for example, partial shading, in which the PV exhibits are normally submitted. Considering the inquiry of the global maximum power point under partial shading, the adequacy of the RPBC - based MPPT procedure is featured when contrasted, and the notable bother and watch MPPT system, since both the said RPBC method is utilized to decide the dc bus voltage reference to guarantee a proper grid-tied inverter task. A current generator method given a synchronous reference outline is proposed, which works in conjunction with a dc-bus controller and MPPT techniques, computing the reference current of the grid-tied inverter. Furthermore, the present generator controls the vitality prepared by the PV framework to keep away from overpower rating of the grid-tied inverter, since the dynamic power infusion into the grid, reactive power compensation and harmonic currents suppression are completed all the while utilizing RPBC technique. The execution and feasibility of the grid-tied PV framework are assessed by methods for simulation and experimental results.***

Keywords--- ***Maximum Power Point Tracking, Grid, Inverter, Robust Power Balanced Controller.***

1. INTRODUCTION

Energy usage has turned into a noteworthy worry as of late because of the quickly expanding request with populace development and industrialization. In spite of this expanding request, enough measure of energy can't be provided, and the look for changed energy sources is formed. Besides, the exhaustion of petroleum products, hustling oil costs, ecological issues of standard energy assets, for example, a common temperature alteration, effect of carbon outflows from non-renewable energy sources ignition and natural contamination guide us to the elective energy sources. On account of the wealth and maintainability of the sun, solar energy is visualized to an important sustainable power source of present and future. Other than having such a significant number of favorable circumstances like simple to introduce, no noise, almost maintenance free, inexhaustible and environmentally friendly; PV frameworks experience the initial effects of the underlying expense of acquiring and introducing PV boards. Since not all the light from the sun is consumed by the solar boards, the majority of them have a 40% productivity of change, and the more significant part of PV boards are around 15– 18% proficient.

Although extensive investigations have been done on expanding PV cell productivity, development rates have still not been at the coveted level. Notwithstanding, it is similarly critical to upgrade the power generation of PV framework by enhancing its MPPT ability. Propelled applications require power converters to exchange the power from PV boards to a utility. These converters can be utilized to direct the voltage and current at the load, to control the power stream in both grids associated and remain single PV frameworks, on a fundamental level to track the MPP of the gadget. So it is the best and reasonable approach to enhance the general PV framework productivity.

Grid-associated PV frameworks are typically made out of PV exhibits, with the end goal that maybe a couple of energy transformation stages are utilized to play out the interface between the PV array and the utility grid. For the most part, the voltage level accessible at the terminals of a given PV array isn't as high as wanted to permit the utilization of a single DC– AC converter to infuse the power delivered by the PV exhibit into the grid. For this situation, the utilization of a first change stage to advance up the PV cluster voltage by utilizing DC-DC converters is essential. Hence, keeping in mind the end goal to diminish the lift proportion required to acquire a high voltage at the significant DC-DC change arrange output, arrangement associations can be utilized. In this way, each DC-DC converter contributes a piece of the aggregate output voltage and, subsequently, a lower boost proportion is required.

In this work, the actualized PV framework is made out of a single change organize, in which the PV array is straightforwardly associated with the grid-tied inverter. The calculation used to play out the MPPT depends on the RPBC strategy. The exhibited RBPC-based MPPT strategy is utilized for following the global maximum power point (GMPP) of the PV array. Not the same as the MPPT strategies in light of the local maximum power point (LMPP, for example, the P&O strategy, a diminishment in the impacts identified with the event of the shadowing

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marvels is accomplished, enhancing the overall PV framework execution. The proposed PV framework method additionally considers the dynamic power separating, to enhance power quality pointers, for example, the power factor, harmonic compensation factor, and others. As such, the previously mentioned markers can intensify because of the expanded utilization of non-direct loads associated with the power supply frameworks.

This work is described out as takes after: First, the demonstrating of research background is portrayed in section 2. At that point, the demonstrating of proposed materials and method is examined in section3. Area 4 represents the result and discussion. At last, the work conclusions are summarized in section 5

2. RESEARCH BACKGROUND

Sustainable power sources, for example, wind and solar are getting to be solid other options to a non-renewable energy source. Keeping in mind the end goal to incorporate these sustainable power sources into the utility network, distributed generation (DG) power frameworks have drawn much consideration from the scholarly community, given their adequacy and consistent quality [1, 2].

Because of the solid necessity of the high energy effectiveness and the adaptability to work in both the grid-associated and island modes, power electronic converters are ordinarily utilized as a part of DG application frameworks.

DG frameworks ought to have the capacity to infuse fantastic current into the grid to satisfy the grid interconnection standard [3], which is regularly guaranteed by the present controller of a grid-associated inverter. Precisely, the control arrangement of a grid-associated inverter ought to be actualized economically, and its plan procedure ought to be deliberate and transparent, for ease to acknowledge it in DG power frameworks.

The crucial part of using a grid-associated inverter is to meet the interface benchmarks as expressed in [4, 5], and to limit the usage cost of the DG frameworks.

Once in the past, the grid-associated inverter utilizes L-type filter as a mean of stifling current harmonics infused into the grid [6, 7].

Lately, in any case, LCL-type filters are more attractive than the L-type filter, because of the littler physical size and better harmonic constriction ability despite the control multifaceted nature. With a specific end goal to protect the power quality, the aggregate harmonic distortion (THD) in infused current needs to meet specific models, for example, IEEE-519 or IEC 61000-3-2, which have been authorized to satisfy the grid integration codes [8-10].

Customarily, to control grid-associated inverters, the direct controllers, for example, the proportional integral (PI) control, have been utilized in the synchronous reference outline, because of their straightforwardness and strength [11-13]. Nonetheless, the ordinary PI decoupling controller does not give legitimate execution in the inverter framework having LCL filters.

Despite the fact that this control plan can guarantee a direct nature of infused current into the utility grid, the decision of controller picks up frequently requires a procedure of experimentation [10].

As different methodologies, the proportional resonant (PR) controller, the prescient controller [14], and the feedback input controller [14-16] have been proposed in writing.

The PR controllers have been generally utilized for grid-associated inverters, because of their ability to dismiss singular harmonics by presenting a vast pick up at a chose resonance frequency [17– 20].

The usage and assessment of a run of the mill PR current controller in an inverter framework was accounted for in [21-23]. With a specific end goal to think about the parameter varieties, a direct discrete-time shaft situation procedure was proposed in [24] for the parameter plan of a PR controller.

Notwithstanding the PR controller, a proficient hybrid damper for a LCL-or LLCL-filter has been displayed for a solitary stage grid-tied inverter, by utilizing the capacitor current input to maintain a strategic distance from the potential shakiness of framework [25-27].

By actualizing numerous PR controllers, chose higher-arrange harmonics can be adequately dismissed. Notwithstanding, the resonant controllers for the most part increment the multifaceted nature and computation weight of the framework.

3. MATERIALS AND METHOD

The block diagram of three phase grid connected solar PV system is shown in Fig. 1.

A three phase voltage source converter (VSC) is used to integrate the solar PV system with the three phase grid. The solar PV panel is connected at the DC bus of the VSC through a boost converter.

The grid and nonlinear loads are connected at the AC side of the VSC through interfacing inductors. The VSC is controlled using a normalized Robust Power Balanced Control (RPBC) algorithm.

This control algorithm is used to estimate reference source current and generates gating pulses to control the VSC.

The VSC is used to control the system voltage and power factor. It also mitigates the harmonic current injected by the nonlinear load into the system. The boost converter used for maximum power point tracking is controlled by an RPBC algorithm.

The VSC is controlling the flow of DC power of PV into AC power.

It also mitigates the harmonic currents injected by nonlinear loads and compensates the reactive power need of the system which in turn control the system voltage at the point of common coupling and improves the power factor.

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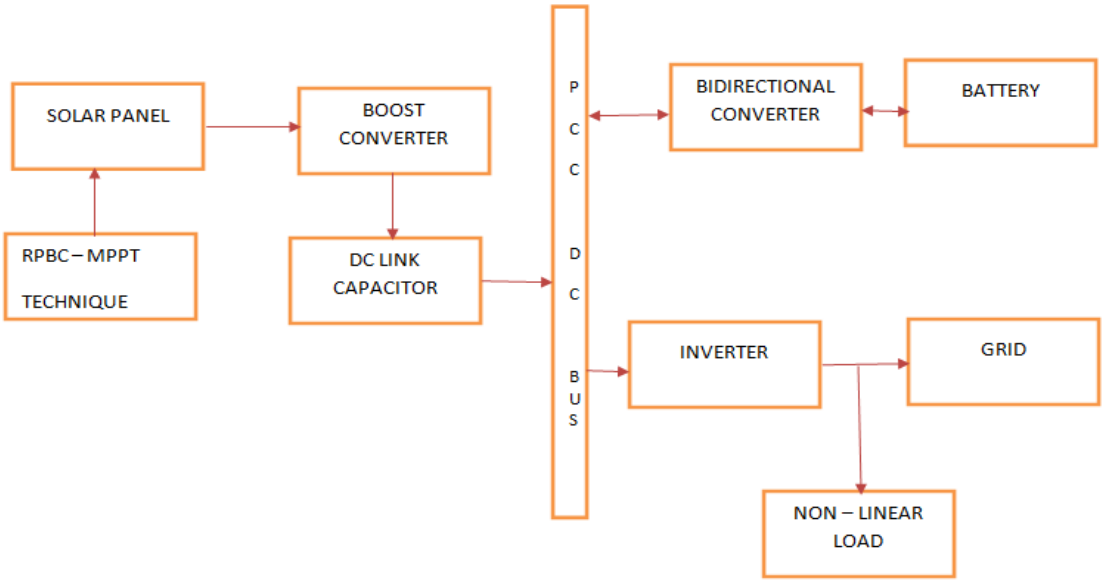

Fig. 1: Block Diagram of the Proposed System

3.1 Solar PV Array

The building block of PV arrays is the solar cell, which is basically a p-n semiconductor junction, shown in Fig.2. The V-I characteristic of a solar array is given by Equation.

$$I = I_{sc} - I_o\left\{\exp\left[\frac{q(V+R_sI)}{nkT_k}\right] - 1\right\} - \frac{V+R_sI}{Rsh} \ldots (1)$$

Where:

V and I = Output voltage and current of the PV, respectively.

R_s *and* R_{sh} = Series and shunt resistance of the cell.

Q = Electronic charge.

I_{sC} = Light-generated current.

Io = Saturation current

N = Dimensionless factor.

K = Boltzmann constant,

Tk = temperature in o^K

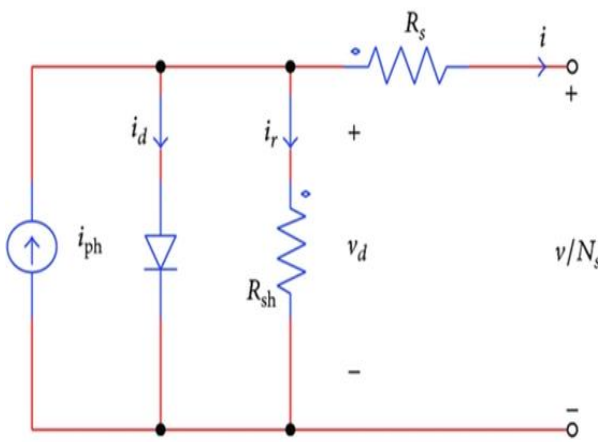

Fig. 2: Equivalent Circuit of PV

Equation (1) was used in computer simulations to obtain the output characteristics of a solar cell, as shown in Fig. 2. This curve clearly shows that the output characteristics of a solar cell are non-linear and are crucially influenced by solar radiation, temperature and load condition. Each curve has a MPP, at which the solar array operates most efficiently.

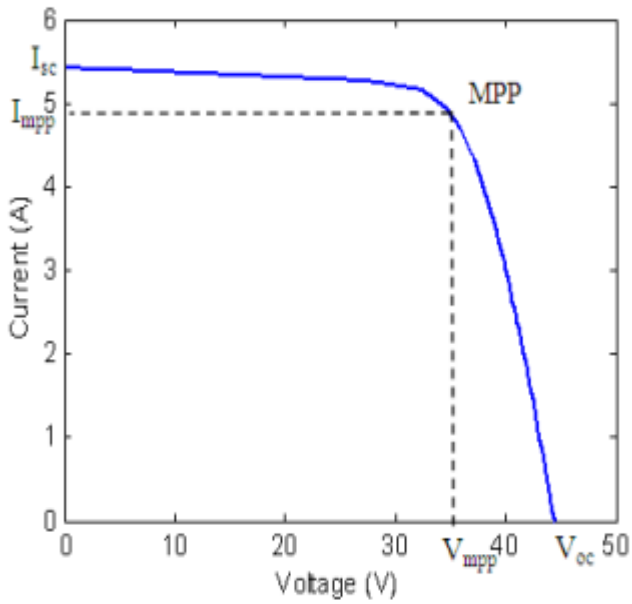

Fig. 3: Characteristics of Solar Cell

3.2 Robust Power Balanced Controller for Maximum Power Point Tracking

RPBC was made given a perception out of P-V trademark curve. This method was wanted to solve the few disadvantage of the P&O technique. RPBC tries to upgrade the following time and to make more power on an enormous light changes condition [4]. The maximum power point (MPP) can be registered by using the association between DI/DV and – I/V. On the distant possibility that DP/DV is negative, by then, MPPT is lying on the right side of the present position, and if the MPP is dynamic, the MPPT is on the left side. The state of IC technique is

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$$\frac{DP}{DV} = \frac{D(V.I)}{DV} = I\frac{DV}{DV} + V\frac{DI}{DV} \text{.....} 2$$

$$\frac{DP}{DV} = I + V\frac{DI}{DV} \text{.....} 2$$

MPP is reached when DP/DV = 0

$$\frac{DI}{DV} = -\frac{I}{V} \text{.....} 3$$

$$\frac{DI}{DV} > 0 \; then \; Vp < Vmpp \text{.....} 3$$

$$\frac{DP}{DV} = 0 \; then \; Vp = Vmpp \text{.....} 4$$

$$\frac{DP}{DV} > 0 \; then \; Vp > Vmpp \text{.....} 5$$

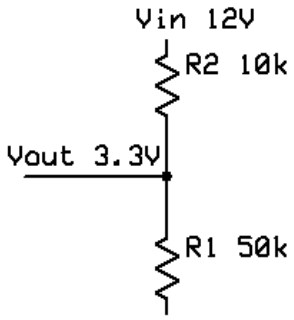

Fig. 4: Voltage Divider circuit

$$Vout = \left(\frac{R2}{R2+R1}\right) x Vin \text{.....} 6$$

Where Bout=output voltage feed to microcontroller taken as 3.3volt, R2=10k ohm R1= resistance that user has to calculate, Vin= open circuit voltage of SPV panel

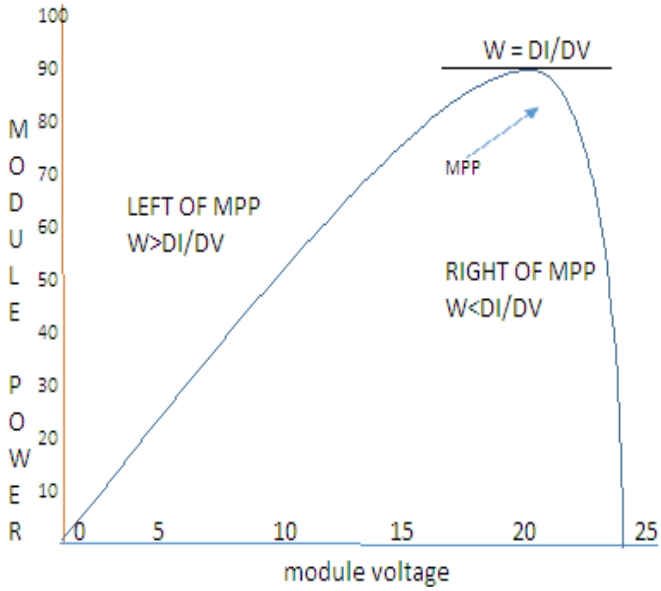

Fig. 5: PV – curve model of solar module using RPBC

The RPBC relies upon the way that the incline of the PV exhibit power curve is zero at the MPP, dynamic on the left of the MPP, and negative on the right, as given by DP/DP = 0 at MPP

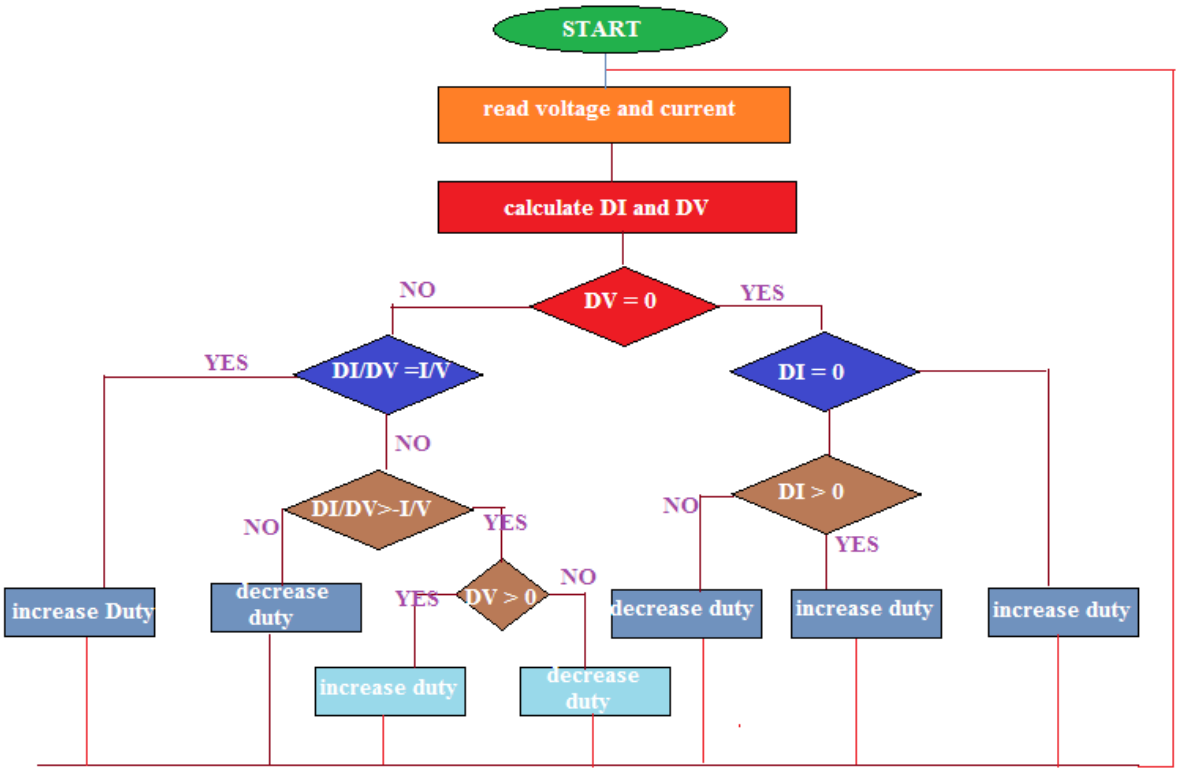

Fig. 6: Flowchart of RPBC – MPPT Method

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RPBC technique can be found in Fig. 6. In case MPP lies on the right side, DI/DV< - I/V and from that point forward, the PV voltage must be decreased to go to the MPP. The IC system can be used for finding the MPP, upgrade the PV capability, diminish control incident and structure cost. Execution RPBC on a controller made an all the more consistent execution when it stood out from Perturb and Observe (P&O). The swaying around MPP zone also can be covered in a trade-off with its use multifaceted nature. The accompanying time still not fast since the voltage expansion and decrement had been picked physically by experimentation.

3.3 Boost Converter

The converter is related to the DC-bus, and the AC-bus as showed up in Fig.7 mentioned above. Its act as a bidirectional converter based on the inverter workflow, where it fills in as an inverter to switch the power from the PV (or the battery bank) to the AC load, and as a rectifier for a circumstance of charging the battery bank from the solar board. The converter is shown in light of its assessed utmost and profitability, which are believed to be steady every through it working reach.

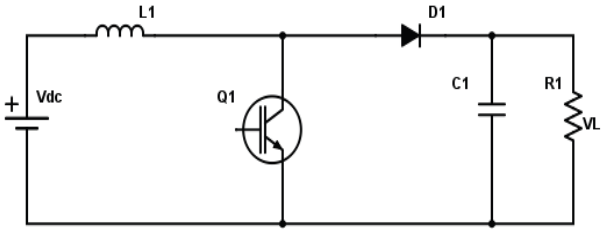

Fig. 7: Boost Converter

The general plan conditions of the boost converter are given below

$$VL = \frac{Vs}{1+\sigma} \dots (7)$$

Where VL is the output voltage, vs. is the source voltage, and σ is the duty cycle. In the continuous conduction mode (CCM) the base inductance of the Lmin is expressed as

$$L_{min} = \left((1-\sigma)^2\right)\sigma Rl\right)2f_s \dots (8)$$

The capacitor esteem is composed to such an extent that the voltage swell Vr as

$$C_{min}\ \sigma/Rlf_sV_r \dots (9)$$

The output voltage relies on the estimation of the obligation cycle which is in charge of the steady output voltage. The load current Io with the duty cycle is expressed with source current Is.

$$I_o = (1-\sigma)I_s \dots (10)$$

The variation of the current ∇I based on the inductance was expressed as

$$\nabla I = V_s(V_l - V_s)/f_sLV_l \dots (11)$$

3.4 Inverter

The DC voltage is changed over into AC voltage, and it is sustained to the BLDC motor.

The inverter utilized here is voltage source converter with PWM method using VTO.

Synchronization must be legitimately done to guarantee the PV panel is nourished appropriately into the BLDC drive. Outline condition inverter is taken after. Base esteem is presented which goes about as reference, and it is given as

$$X_b = (E_n)^2P_n \dots (12)$$

$$B_b = 1/(W_nZ_b) \dots (13)$$

$$W_n = W_b \dots (14)$$

Where

W_n = Grid frequency, E_n = RMS Voltage and P_n = Active power. The DC side Capacitor is selected based on following conditions.

1. Time delay which is introduced by filtering of the DC voltage and Current control Tr.
2. DC voltage variation ΔV_0
3. Maximum power variation ΔP_{max} on the dc bus
4. Load ride through ability and assurance amid utility voltage hang occasions The DC capacitor can be planned to utilize the accompanying condition

$$C \geq \frac{Tr\Delta Plmax}{2V_0\Delta V_0} \dots (15)$$

An LCL channel arrangement is actualized to take out the switching frequency harmonics given the angle of the voltage and current sensors the capacitor variably affects the framework.

The AC side capacitor value is calculated as

$$C_f = l - \frac{lG}{2b^2} \dots (16)$$

The magnetic core used for the design of inductor is made up of following materials laminated metal alloy, iron, ferrite and powdered metal. The present ripple produced by the VSC is restricted by the inductance L which is on the converter side. The present ripple is expected to the VSC switching. The converter side inductance is given by the underneath condition.

$$l = \max\left(V(n)/nW_bI_{Limit}(n)\right) \dots (217)$$

Where v (n) – voltage generated at n-harmonic by the VSC and $I_{Limit}(n)$ is the maximum passable current ripple at the n-frequency. The satisfactory switching ripple is utilized to decide the inductance lg at the inverter side.

3.5 Robust Power Balanced Control (RPBC) Technique Synchronize the Grid and PV Panel

To have a safe and cost-efficient power generating system, an optimization algorithm based on altruistic transformative algorithm has proposed. Fig. 8 shows the diagram of the proposed algorithm in which the RPBC block represents the robust power balanced control (RPBC) technique

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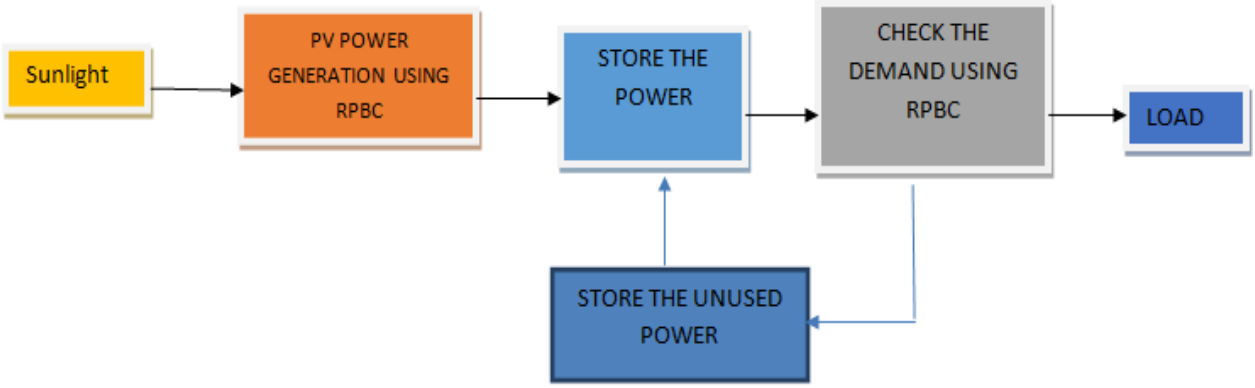

Fig. 8: Robust power balanced control (RPBC) technique optimization algorithm's diagram

Photovoltaic is very first generation is created by "Generate Power." The generated power is compared with demand power if it is larger than the request than with the comparatively good fitness (f>1) it goes to the processes of RPBC. If the generated power does not match input demand (lower power than load), the comparison code produces a relatively low fitness (f<1) then continues with RPBC optimization process. Since the RPBC generates and keeps parameters with the best fitness, it makes as much power as the demand. The cost values have considered by the algorithm such that the lowest cost solution which meets the demand has produced.

The optimization methodology to determine the configuration and sizing for hybrid energy sources, simultaneously considering economic, technical and environmental objectives as well as satisfying three constraint conditions, was developed using the altruistic transformative algorithm.

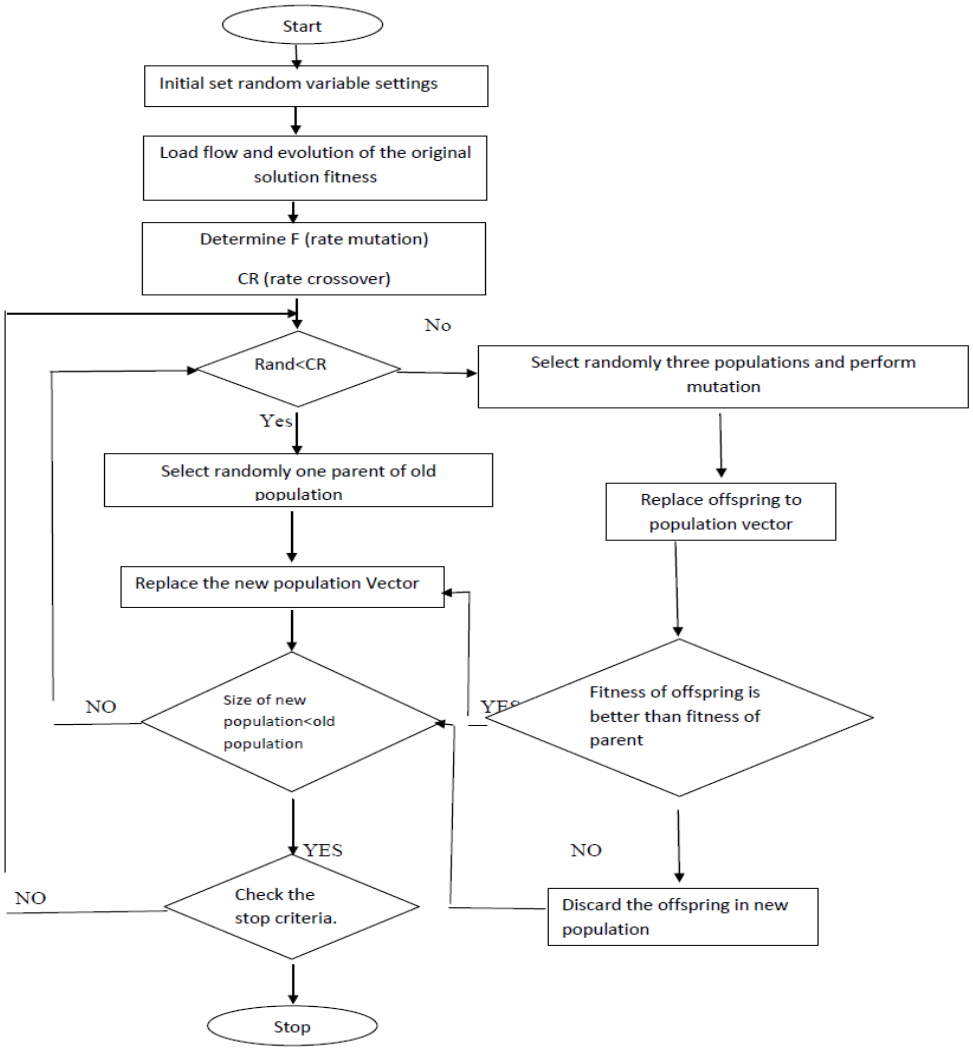

Fig. 9: Flowchart of RPBC

This technique is recognized as one of the most powerful evolutionary algorithms for real number function optimization nowadays. The RPBC algorithm has explained in the following steps which shown in Fig. 9.

3.6 Optimization of Solar and Grid Algorithm Steps Using RPBC

Step I (initialization): puts the iteration t=0 and generates the randomly m parameters.

$[X_i(0), i = 1, \dots., m], X_j\ (0) = [\ X_j 1(0), X_j 2(0), \dots. X_j n(0)] X_{jr}(0)$ Will generate in searching space $[Xr^{2min}, Xr^{max}]$ randomly.

Step II (mutation): Generate a random integer for F

Step III (fitness): evaluating each parameter in the initial parameters using the objective function. **Step IV (time update):** updates the time counter t=t+1.

Step V: generate another parameters by repeating by the following steps until the parameters is done:

Step VI: Create a random integers is CR (crossover) (Mutation) randomly select three parameters from $X_j(t)$ such that $X_j, r1(t)\#, r_2(t)\#, r_3(t)$ A sample vector $y_i(t)$ is denote as $y_i(t) = X_j, r_1(t) + F(X_j, r_2(t) - X_j, r_3\ (t))$ (Crossover) candidate vector $[\ X_j(t), j = 1 \dots n]$ is obtained through crossover operator involving the vectors $X_{j,i}(t)$ and $y_i(t)$ is defined as:

$$X_j(t) = \begin{cases} y_i(t)\ if\ rand\ (0,1) \leq CR \\ X_j, i(t)\ if\ rand\ (0,1) > CR \end{cases}$$

The collection methods involve a straightforward replacement of the original parameter vector with the applicant vector if the concern function decreases by such an action. If current parameters are less than old community, the operation has continued. Else go to step6.Step6 the process will stop if one of the stopping criteria was detected, else go back to step2

3.7 Apply RPBC for Power Quality Problems

The application of RPBC on the power quality problem with custom power distribution devices is presented. To apply the RPBC algorithm to solve this problem, the following steps should be taken and repeated.

Step 1: Generate the initial parameters. The initial parameters for each iterate are randomly generated as follows:

$$population = \begin{bmatrix} X1 \\ X2 \\ \dots. \\ Xf \end{bmatrix}$$

$$Xi = [Vstack\ , Vpv\ , Ppv\ , \cdot_{custom\ parameters}\ , Qc]$$

Where Vstack and VPV are voltages of the slack bus and PV buses respectively, PPV is active power generation of PV buses, $CUSTOM_{parameters}$ involve angles of shunt converter, series converter and amplitude of series converter and QC is reactive power value of the compensator capacitor.

Step 2: Calculate objective function value for each parameter.

Step 3: Sort the initial parameters based on the objective function values with decreasing manner

Step 4: dividing sorted parameters in meme lexes by the following process, and the first parameters go to the first memeplex, the second parameters goes to the second memeplex, parameters q^{th} goes to the qth memeplex, and parameters q + 1 goes back to the first memeplex, etc.

Step 5: Select the best and worst parameters in each memeplex and generate.$_b$s the and X_w for them respectively.

Step 6: the frog with the global best fitness in all meme lexes is identified as Xg.

Step 7: a process is applied to improve only the frog with the worst fitness according to, if this process produces a better solution, it replaces the worst frog. Otherwise, a new parameter is randomly generated to replace that parameter. This process continues for a specific number of iterations (itetationmax1)

Step 8: in this section, all meme lexes are combined and sorted again.

Step 9: apply mutation to compensate RPBC drawbacks mentioned in the previous section.

Step 10: If the current iteration number (iterationmax2) reaches the predetermined maximum iteration number, the search procedure is stopped. Otherwise, it goes to Step 4.

Step 11: The last Xg is the solution to the problem.

4. RESULTS AND DISCUSSION

As per the Simulink model of a proposed system utilizing MATLAB2017a software to construct different free functional modules, and coordinated into the simulation model of a BLDCM control framework. In the MATLAB/Simulink condition, using the inherent capacities and M Systems display library SimPower to set up the entire BLDCM framework demonstrate, which is appeared in Fig. 10.

The above figure 11 representations the Simulink screen of solar grid control utilizing robust power balanced control system. The instant controller reproduction comes about are talked in following figures.

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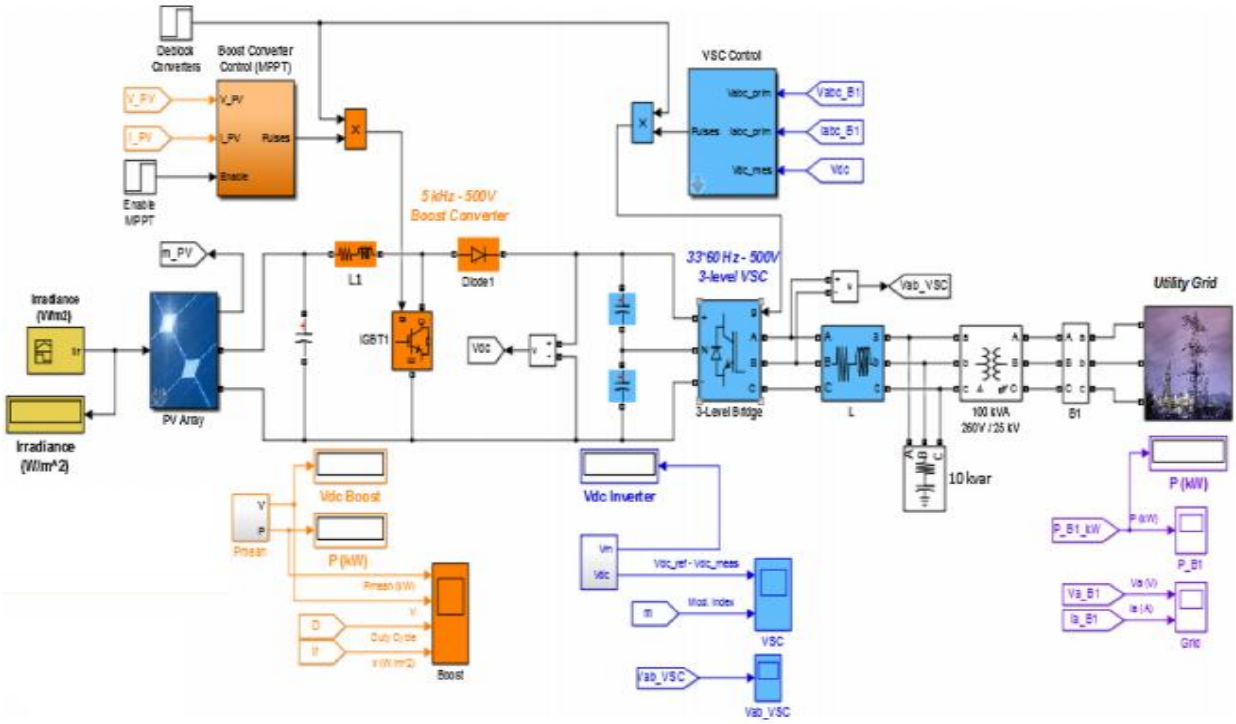

Fig. 11: Simulink Model

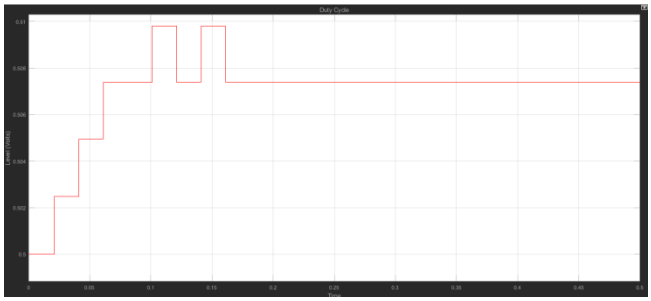

Fig. 12: Duty Cycle

The above mentioned Figure 12 shows the duty cycle in MPPT – Robust Power Balanced controller to control a duty cycle of PWM signal generator.

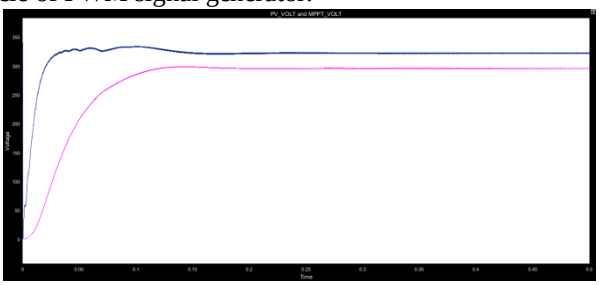

Fig. 13: PV Voltage and MPPT Voltage

The above depicted figure 13 shows the PV voltage and MPPT voltage. From this figure blue line indicates the maximum power point output using RPBC method.

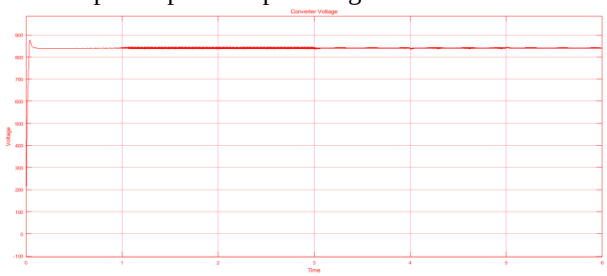

Fig. 14: Converter Voltage

The above figure 14 demonstrates the boost converter voltage of the proposed framework. The DC to DC converter that delivers an output voltage more prominent than, not precisely, or equivalent to that of its input voltage. The output of the boost can be controlled by the duty cycle of the control MOSFET

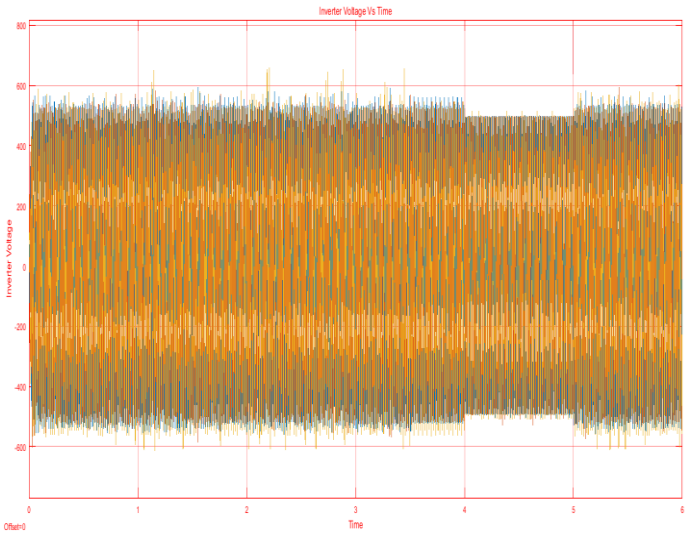

Fig. 15: Inverter Voltage

The fig said over 15 demonstrates the corresponding grid voltage reaction of the proposed Adaptive tolerant distributed control procedure. In this system was shows that the variety of framework frequency is inside the limit of synchronization framework frequency for the activity of the interconnected framework.

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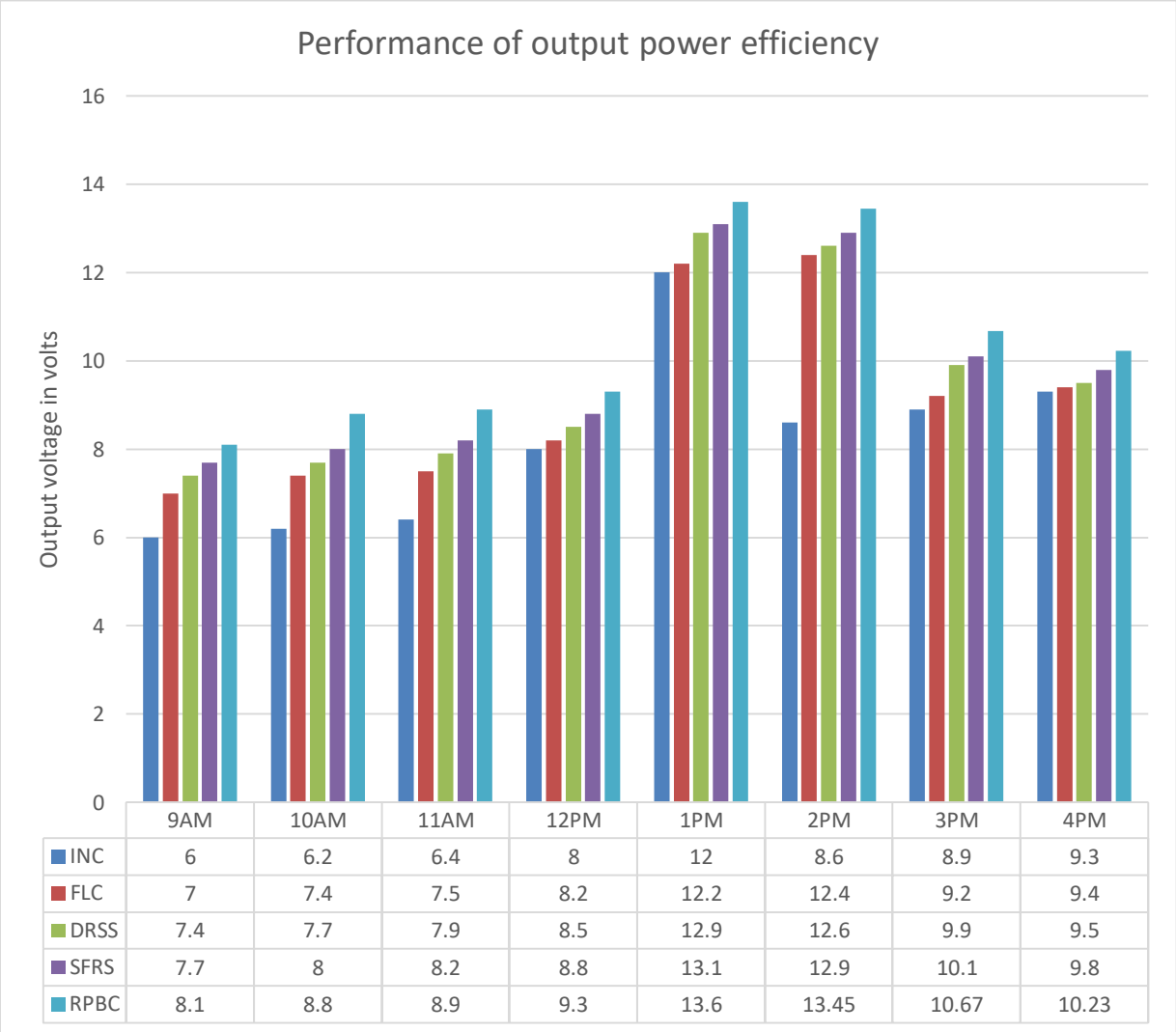

Fig. 16: Output solar Power generation Comparison

Fig 16 Is Giving the Information about Output Voltage Hourly Comparison of Existing and Proposed Method on Change in Environmental Conditions.it is apparent that the power varies with time of the day in existing and proposed methods. As compared to the existing process the proposed method produces the maximum power. From the investigation of reproduction results in the different parameters, for example, switching losses, maximum Output power and efficiency estimations of converters are recorded in Table 4.1. Conventional Incremental conductance (INC), Fuzzy (FLC), SFRS and RPBC Controller have the Efficiency values of 84.72%, 89.55%, 94.92% , 99.25% and 99.98 respectively. The Comparison table shows the efficiency of the proposed under a different level of control index.

Table 4.1: Comparison Table of the Proposed Model

S.No	Controller used	Output power in per unit	Switching Losses (%)	Maximum output Power Efficiency (%)
1	Conventional MPPT using INC method	0.84	16	84.72
2	Fuzzy logic controller	0.89	11	89.55
3	Dynamic Rule soft switching Controller	0.94	6	94.92
4	SFRS control	0.98	4	99.25
5	Proposed RPBC	1.02	3	99.98

Maximum power tracking Efficiency comparison of different converters with proposed converter system is shown in the graph below.

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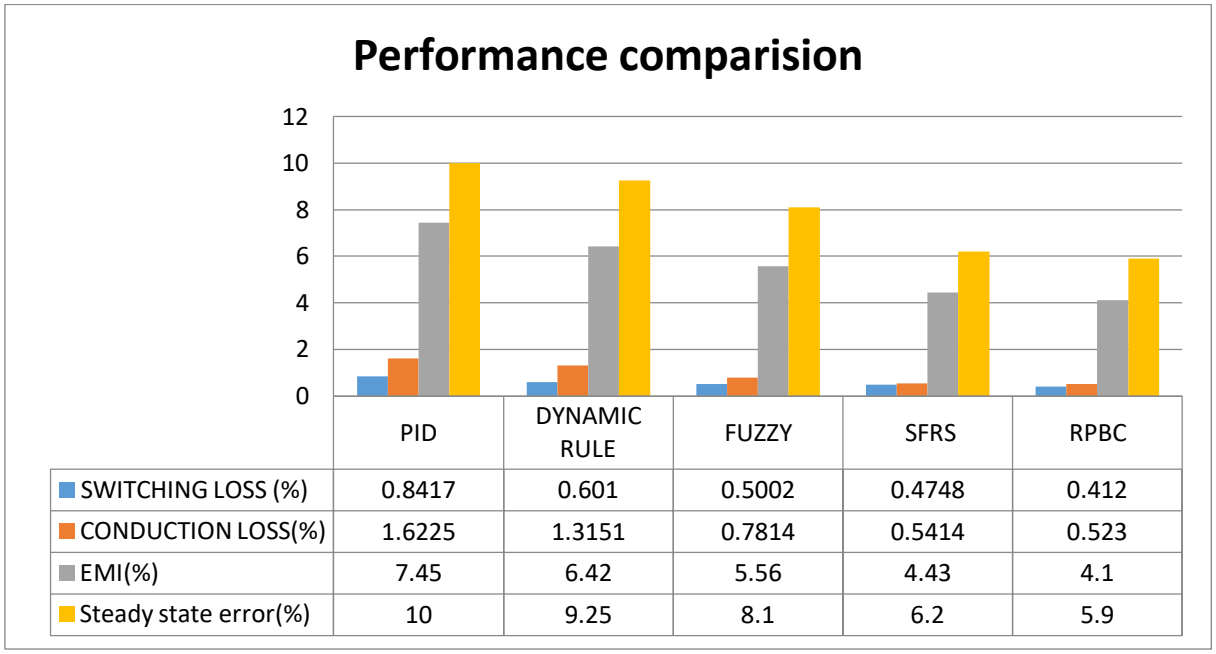

Fig.17: Performance comparison

Figure 17 demonstrates the performance analysis between different algorithms, and it indicates that the advanced, sophisticated distribution control algorithm has created effective than other techniques. From the above all analysis performed, the proposed sophisticated distribution control method has been evaluated with various parameters and has produced accuracy results as compared to other conventional techniques.

5. CONCLUSION

A Robust Power Balanced Controller scheme for power quality improved three phase grid connected solar PV system has been successfully presented in this work. This scheme is found highly suitable for the control of voltage and power quality improvement in a three phase grid interfaced solar PV system. The THD in grid current is found to be less than 5% therefore the system is meeting IEEE-519 standards of power quality. The normalized RPBC controller has significantly improved the dynamic behavior of integrated three phase system and regulates the voltage while system is feeding highly fluctuating loads. The suggests that the RPBC version advanced in this paintings can predict the MPP for a PV panel with extreme accuracy. Moreover, results of the proposed RPBC shows better transient performance, with low over- shoot, compared to the results obtained from the literature. Simulation results have been accomplished by developing a de- tailed dynamic hybrid system model. Real-time measured parameters and practical load profile are employed as inputs to the improved management system. It was determined that the hybrid topology exhibits superior performance under various operating conditions, and maintain the SOC between 40% - 80%.

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