SUPERIOR POWER QUALITY ENHANCEMENT IN DISTRIBUTION LEVEL INTERCONNECTED SOLAR ENERGY SYSTEM CONTROLLED BY ULTRACAPACITOR INSTEAD OF DC LINK CAPACITOR

R.Srinivasan., M.E.,(Ph.D.).[#1],Dr.R.Arulmozhiyal.,M.E.,Ph.D[*2].,
[#1] *Research Scholar,* [*2] *Professor, Dept.of Electrical and Electronics Engineering,*
[#1] *Anna University, Chennai, Tamilnadu, India* [*2] *Sona College of Technology,Salem, Tamilnadu, India*
[#1]pavishsrini@gmail.com[*2] arulmozhiyal@gmail.com
M.Yogaselvi, M.E.(PED) [#3]
[#3] PG Scholar, Dept of Electrical and Electronics Engineering, Anna University, Chennai. *Tamilnadu, India*
[#3]m.yogaselvi@gmail.com

Abstract: *This research paper presents a new approach for achieving maximizing the utilities from the grid-interfacing inverters using the modified PI controller viz., AWPI and SMC controller. When installed 3-phase 4-wire distribution systems to achieve the voltage profile of system. Usually, the photovoltaic energy sources generate power at variable low dc voltage, Thus, the power generated from these renewable sources are interconnect using various converters before connecting on dc-link. In this proposed work, a maximum power point tracking (MPPT) scheme has been used to obtain maximum power from the renewable energy system and DC/DC converter is implemented to maintain a constant DC voltage. The universal inverter is controlled to perform as a multi-function device by incorporating active power filter functionality. System transients are suppressed and normal conditions are quickly restored with shunt APF and Ultracapacitor instead of DC link capacitor. So, it can be concluded that Ultracapacitor based energy storage technology can be used to enhance the operating capability of APF to maintain high quality grid voltage. Ultracapacitor is very fast in charging and discharging compared to traditional DC link capacitors which is needed to restore the system. Finally, the performance of the system can be analyzed and implemented by incorporating Sliding Mode Controller (SMC) and Anti-windup PI (AWPI) controller with modified ultra-capacitor filter circuit in the PI Controller. This new control concept is demonstrated with extensive MATLAB / Simulink.*

Key words: *DG, Grid Interconnection, Power Quality, Distribution, Renewable Energy Sources, THD.*

I. INTRODUCTION

The system behavior is severely disturbed, due to the problem arising in the voltage or current profile, flickering of voltages, harmonics and further spins in the output of the sine waveform, which leads to power quality in the system. In electrical power system, always the voltage and current have the close relationships. Most of the generation station can maintain the voltage profile, but load is the sole responsibility for the current profile.

Always we are giving the importance to irregular increase of current imbalance and harmonic distortion leads to increase of reactive power consumption. The voltage harmonics and disturbance in the electric grids can make the flow of harmonic current. The distortion of voltage in the system can cause only by the leakage current flowing through the system.

In modern power electronics controlled industries introduces the power quality issues and it is mainly dominated only by non-linear loads. Load operation and system parameters profile studies are helpful to understand about the system performance and harmonics in the system. In power quality problem, the reactive power consumption is plays a major role of issue in commercial consumers like industry.

In transmission and distribution systems, the high value of RMS current are caused by reactive power consumption of the inductive loads and also it can produce the heat. The reactive power and the harmonics of the system are compensated by shunt active filters. In addition to this, the DC link voltages are also enhanced and the DC capacitor is replaced by ultra-capacitor to improve the DC bus voltages and reduces the ripples and peak overshoot of the system.

II.PROBLEM IDENTIFICATION

The basic idea is to maintain the performance of the system by controlling the DC link voltage using PI controller. In PI controllers, provides relatively large output due to absence of magnitude limiters, by providing the limiters for saturation and magnitude, it causes the large overshoot and increasing the settling time and leads to instability of the system.

- To enhance the system performance with modified PI controller [7] viz., AWPI. The system performance can be improved further by including a non-linear control methodology viz. sliding mode control technique (SMC).
- The novelty of the system can be achieved by making some modifications in the modified PI controller and changes in the DC voltage filter circuit. The filter circuit consists of capacitors, which can be modified, as ultra-capacitors instead of ideal capacitors.
- Finally, the system performance like settling time, steady state problem and THD values were improved using SMC controllers [2] and AWPI controllers [3]. Even though all the controllers having their own merits and demerits, in this research AWPI controllers is used for simplicity, Good performance and robustness and SMC controllers is used for system disturbances are insensitive in controlled system.

III .ROLE OF DC LINK CAPACITOR AND ULTRA-CAPACITOR

In this system, DC link capacitor plays a major role; it used to maintain the dc voltage for improving the system performance like settling time, THD and steady state problems.

As shown in the fig.1, A DC link performs a role to transferring a power with variable nature from solar system to DC link then grid through inverter. Because of variable nature of solar system it will be represented as a current source. The current delivered from solar system can be given as

$$I_{Solar} = P_{Solar} / V_{dc} \quad .....(1)$$

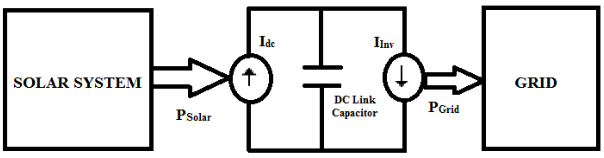

Fig. 1.Equivalent diagram of DC link circuit

Where as P_{Solar} is the power of solar system

$$I_{Grid} = P_{Inv} / V_{dc} \quad .....(2)$$

Here considering the inverter loss is negligible. The Ultra-capacitor and DC link capacitor are comes in the same electro chemical category. But the characteristics of both the device are not same due to operating principle. The Ultra-capacitor has the lower energy density; life of the UC's is over than one million cycles and higher power density than batteries. It can be used to reduce the settling time of the system and provides the constant output in DC side of the inverter.

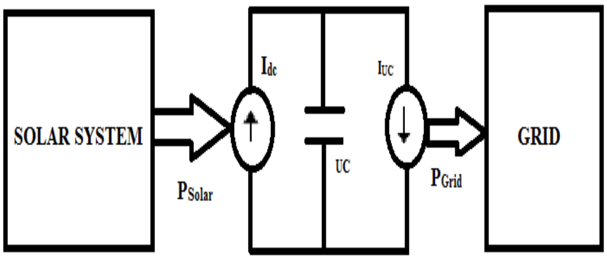

Fig. 2.Equivalent diagram of Ultra-capacitor

As shown in the fig.2, The DC link filtering circuit can be replaced by the ultra capacitor instead of DC link capacitor for performing better than ordinary capacitor. The value of ultra-capacitor has the value in hundreds of farad and the size of ultra-capacitor is small as compared with conventional capacitor. It can provide the dynamic response and improves the stability of the system. For improving the above discussed things, in this proposed system the DC link capacitor is replaced by ultra-capacitor [8] and performances were discussed below section.

IV. DESIGN OF ULTRA-CAPACITOR

Typically the ultra-capacitor differs from DC link capacitor; it has double layers and working voltage of between 1v to 3v. The construction of ultra-capacitors effectively creates a two series capacitor.

The energy stored in the ultra-capacitor is,

$$E = ½ CV2 \quad .....(3)$$

Where the E is referred as energy stored in joules
C is the capacitance and
V is the voltage across its terminal.

As compared the capacitor lifetime with ultra-capacitor, it has more than one million charge cycles. The ultra-capacitor it does not have any harmful chemicals and toxic metals. The capacitance value of ultra-capacitor is in the range of hundreds of farads. For attaining the desired capacitance and voltage of ultra-capacitor it is formed by M is the no. of columns and N is the no. of the rows.

Capacitance, C = Ccellx (M / N) and V = Vcellx N.

Normally, the power density range of the batteries indirectly increases cost of the battery. But in ultra-capacitor it has high power density and cost is less as compared with conventional capacitor. In this paper, the ultra-capacitor is designed for 42V and to attain the desired 230 V in DC bus six ultra-capacitors are connected in series.

V. SYSTEM DESCRIPTION

The fig.3 shows the block diagram of proposed methodology with PI controller. The power generated from renewable energy sources (Solar System) using boost converters and maximum power point tracking method is utilized to obtain maximum power from solar energy [5]. Then power is fed to universal converters through ultra-capacitor, not like DC link capacitor. Finally, power is injected to the load or may be to grid [1]. As compared with DC link capacitors, ultra-capacitors is fast in charging and recovers the system from fault as quick as possible.

In this proposed method, First of all Pi controller is used in the renewable energy system [4]. Because its gives the fast dynamic response, easy and so simple in implementation. In PI controllers, provides relatively large output due to absence magnitude limiters, by providing the limiters for saturation and magnitude, it causes the large overshoot and increasing the settling time and leads to instability of the system.

For improving the stability of the system parameters like voltage and current and to reduce the maximum overshoot of the system, thus the AWPI and SMC controllers are introduced and analyzed. The output values of Pi, SMC and AWPI controllers with Universal Controllers are evaluated.

The universal converter used as a power injector to the grid or load and to reduce the voltage, current imbalance and harmonic distortion in addition to selective reactive power compensation in system like active shunt filter. The peak overshoot and settling time of each controller with renewable energy sources are tabulated and briefly discussed with the help of MATLAB 2013a.

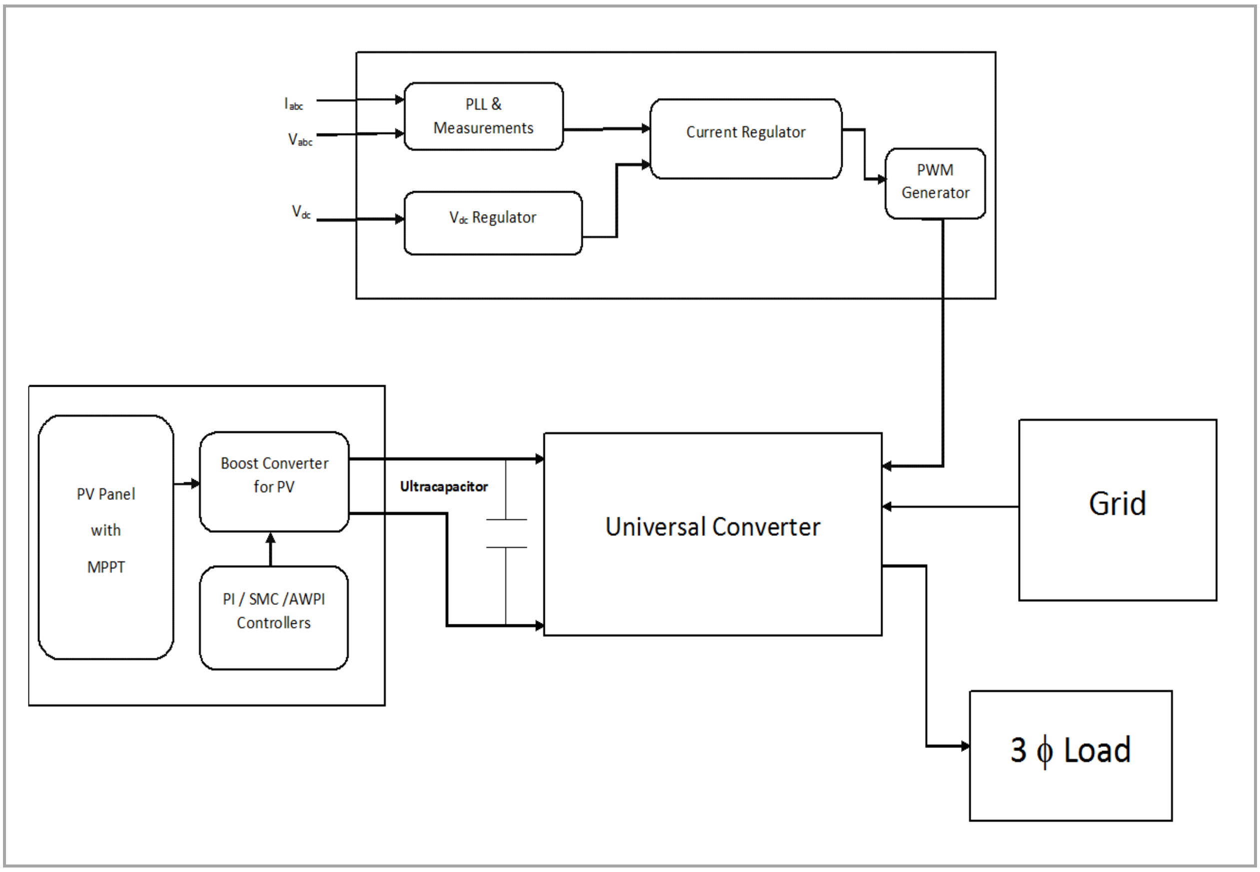

Fig. 3.Proposed overall block diagram

TABLE II
Performance of Controllers with Ultracapacitor and DC link capacitor

S.No	Type of Controller	Controllers With DC link capacitor			Controllers With Ultracapacitor		
		Peak Overshoot (V in volts)	**Settling Time**	**Final Value at t= 0.6 sec**	**Peak Overshoot (V in volts)**	**Settling Time**	**Final Value at t= 0.6 sec**
1.	Pi Controller	1133.169	0.3	723.7496	1057.659	0.3	678.2019
2.	Pi and SMC Controller	500.8875	0.1	520.8311	471.2117	0.1	490.8591
3.	Pi and AWPI Controller	501.0991	0.1	523.5259	473.1337	0.1	493.8176

VI. ANALYSIS OF UC CAPACITOR BASED VARIOUS CONTROLLERS

The performance of system using Pi, SMC and AWPI controllers as given in table II. The Detailed analysis of three controllers with DC link capacitor and Ultra-capacitor as given above in tabulated format.

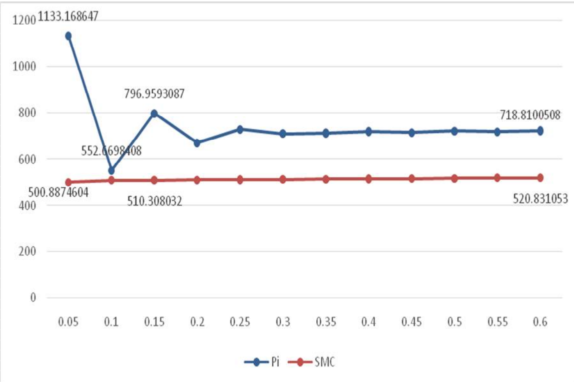

Fig. 4. Peak Overshoot for Pi and SMC Controller with DC link capacitor

From the above Fig.4, refers the analysis of PI and SMC controllers with DC link capacitor. As shown in the Figure the peak overshoot values of Pi is 1133.16 and With SMC controller is 500.88 for the controllers connected with DC link capacitor. The same two controllers with ultra-capacitor the peak overshoot is 1057.65 and 471.21 respectively it is clearly seen in the figure.5.

It shows the value of peak overshoot is gets reduced due to change in controller and further value is reduced connecting the ultra-capacitor instead DC link capacitor. As compared with Pi is having the high peak overshoot as compared with SMC controller. Further the Pi controller is evaluated with AWPI controller as follows.

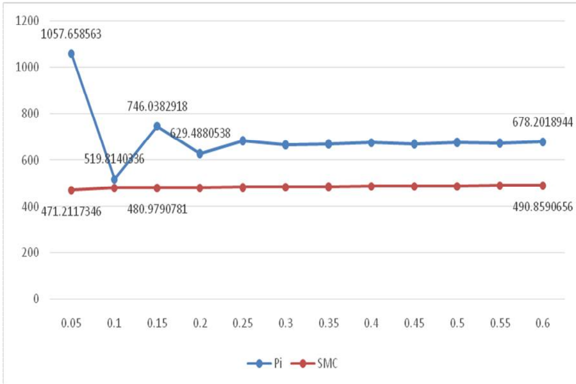

Fig. 5. Peak Overshoot for Pi and SMC Controller with UC

From the Fig.6, the analysis of PI and AWPI controllers with DC link capacitor. The peak overshoot values of PI is 1133.16 and With AWPI controller is 501.09 for the controllers connected with DC link capacitor. The same two controllers with ultra-capacitor the peak overshoot is 1057.65 and 473.13 respectively it is shown in the Fig.7.

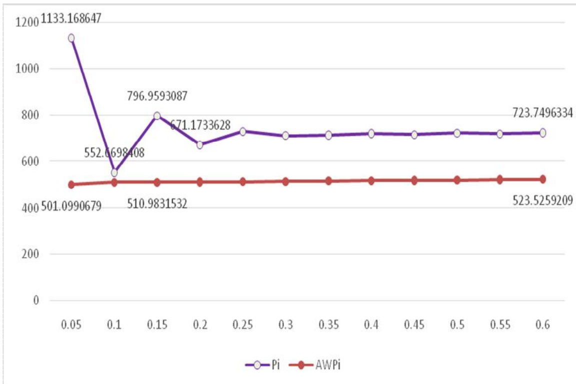

Fig. 6. Peak Overshoot for Pi and AWPI Controller with DC link capacitor

It shows the value of peak overshoot is gets reduced due to change in controller and further value is reduced connecting the ultra-capacitor instead DC link capacitor. As compared with Pi is having the high peak overshoot as compared with SMC and AWPI controllers.

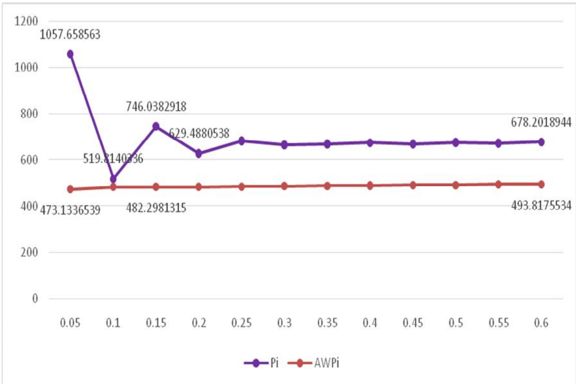

Fig. 7. Peak Overshoot for Pi and AWPI Controller with UC

From the figure 4, 5, 6 and 7 gives the analysis of peak overshoot value, settling time and the final value of the Pi, SMC and AWPI controllers with DC link capacitor and ultra-capacitor respectively.

In this proposed system, DC link capacitor is replaced by an ultracapacitor, it used to maintain the dc voltage at DC link for improving the system performance like settling time and DC link voltage.

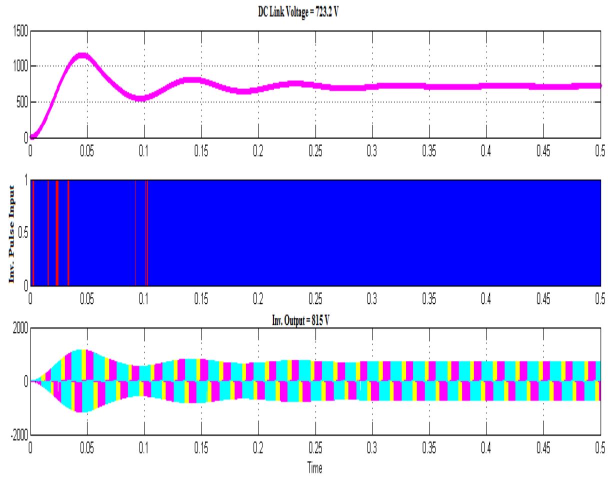

Fig. 8. DC link voltage and Output of the inverter with conventional capacitor

The figure 8 shows the snapshot is related to the system is interconnected with DC link capacitor and it provides the DC link voltage of 723.2V and the inverter output of 815V and the settling time is 0.6 sec. The figure 9 shows the snapshot is related to the system is interconnected ultracapacitor and it provides the DC link voltage of 677.5V and the inverter output of 815V and the settling time is 0.45sec.

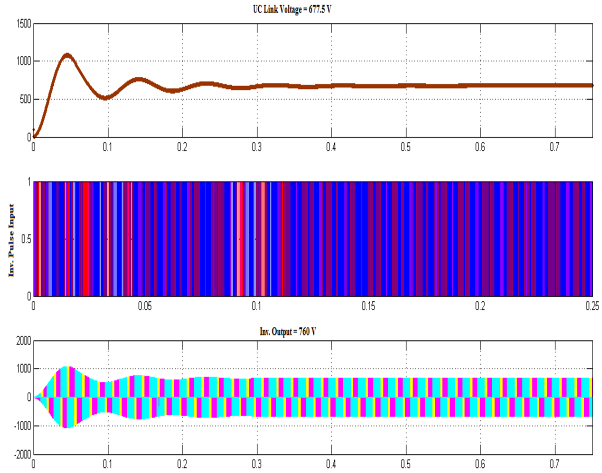

Fig. 9. DC link voltage and Output of the inverter with ultracapacitor

For Analyzing the THD performances of three controllers, a load of 15KVA with 0.95 pf are connected with the system. As comparing the parameters of a system, the accuracy and precision is a major issue in the controller design. Because, most of the systems are having the non- linear property only. So, here THD values of three controllers for the load current are analyzed with DC link capacitor and Ultra-capacitor.

TABLE IV
THD comparison of controllers with DC Link Capacitor

Type of Controller with DC link capacitor	Type of Renewable Energy Source	%THD for Iload With DC Link	%THD for Iload With UC
Pi Controller	Solar	0.80	1.53
SMC Controller	Solar	1.60	1.69
AWPI Controller	Solar	0.96	0.24

The table III provides the THD values of three types of controller with the DC Link capacitor and Ultra-capacitor.

The figures 10 and the figures 11 briefly give the details about the THD value of each controller with DC link capacitor and Ultra-capacitor.

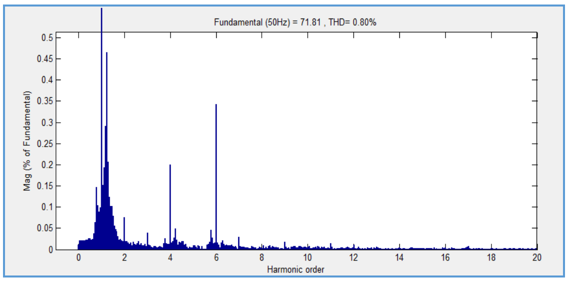

Fig.10(a). THD values of Pi controller with DC link capacitor

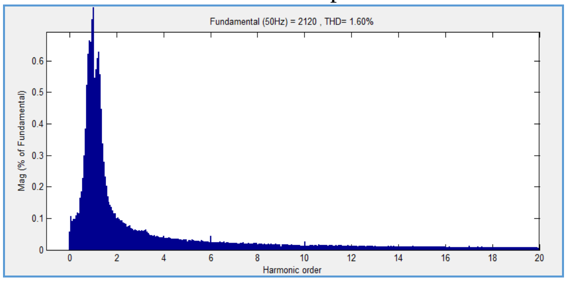

Fig.10(b). THD values of SMC controller with DC link capacitor

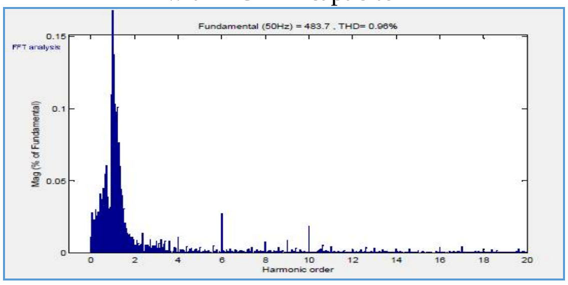

Fig.10(c). THD values of AWPI controller with DC link capacitor

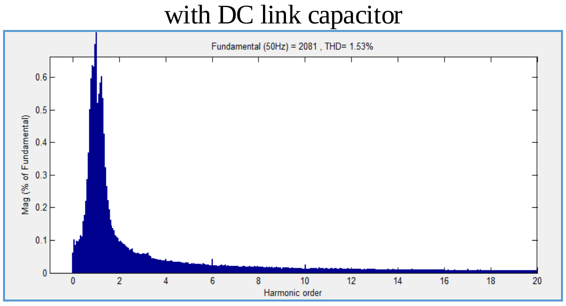

Fig.11(a). THD values of Pi controller with Ultra-capacitor

In the figure 12(a), (b) and (c) shows the THD values of Pi, SMC and AWPI controllers are 1.53%, 1.69% and 0.24 respectively. In this analysis the AWPI controller provides the 1.31 % THD lesser than the Pi controller.

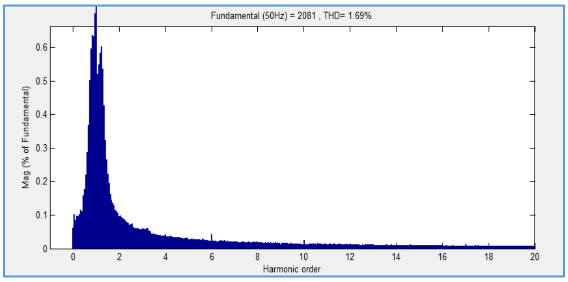

Fig.11(b). THD values of SMC controller with Ultra-capacitor

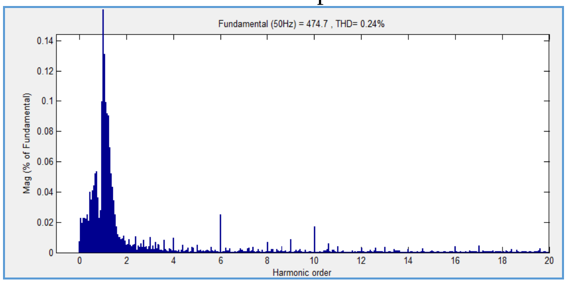

Fig.11(c). THD values of AWPI controller with Ultra-capacitor

VII. EXPERIMENTAL VALIDATION

TABLE V
Comparison of DC link voltages and Ultracapacitor Voltages

FROM SIMULATION RESULTS					
S.No	Type of Ctrler.	Voltage With DC link capacitor (In Volts)		Voltage With Ultracapacitor (In Volts)	
1.	PI	Peak overshoot value	Inverter DC input value	Peak overshoot value	Inverter DC input value
		1133.16	718.81	1057.65	678.20
FROM EXPERIMENTAL RESULTS					
S.No	Type of Ctrler.	Voltage With DC link capacitor (In Volts)		Voltage With Ultracapacitor (In Volts)	
2.	PI	Peak overshoot value	Inverter DC input value	Peak overshoot value	Inverter DC input value
		1098.23	699.25	1022.91	666.73

The figure 12 shows the hardware set up of prototype model with 500va solar energy based grid connected inverter with ultracapacitor. For our easy experimental purpose, the supply voltage consider as a grid. For validating the simulation results, the prototype PI controller system is built with DC link capacitor and Ultracapacitor. In this prototype, the solar panel injects the variable voltage to the grid through boost converter and Inverters. The battery backup is provided in the prototype model for providing the continuous The DC link capacitor acts as a power condition device which provides the path to the variable voltage available at renewable energy system side to the grid side.

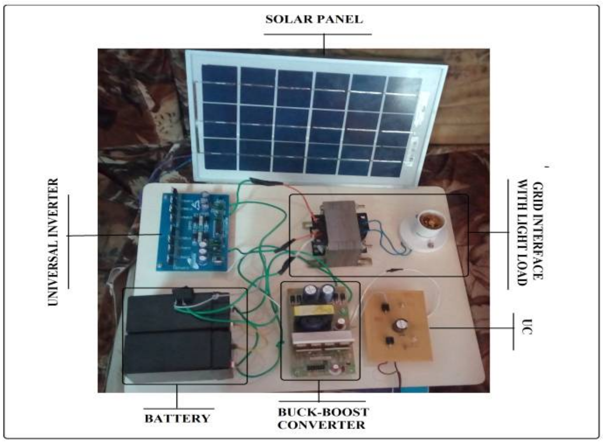

Fig. 12. Hardware setup

Here the DC link capacitor is used and the peak overshoot value is 1098.23. For reducing the peak overshoot voltage, the DC link capacitor is replaced by an Ultracapacitor. The value of Ultracapacitor is 3F. The value of peak overshoot is 1022.91 with Ultracapacitor and 1098.23with DC link capacitor. The simulation and experimental values are tabulated in table V.

Fig. 13. Ultra capacitor link voltage

The voltage of DC link voltage is improved and filters out the variations of DC voltage earlier processed by the inverter section of the system. The output voltage of ultracapacitor link is 667V prior to inverter and then it is processed by the inverter. The output voltage of the inverter of renewable energy source is 689V.It is clearly shown on the figure 13 and 15 respectively.

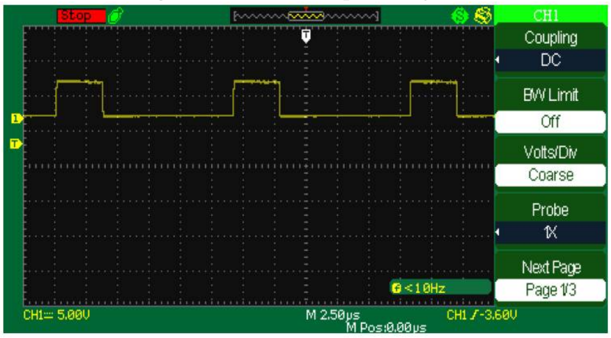

Fig. 14. Input Pulse to Inverter

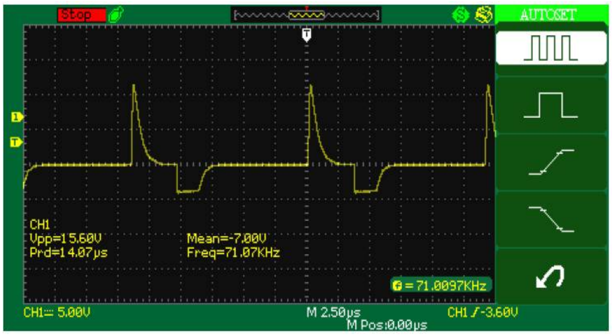

Fig. 15. Output voltage (Vinv) of the Load

VIII. CONCLUSION

This paper presented a new unique control strategy for achieving maximum benefits from these grid-interfacing inverters using the modified PI controller viz., AWPI and SMC controller, where installed in 3-phase 4-wire distribution systems achieves a high quality load voltage profile of system and efficiency of the inverter using ultra-capacitor instead of DC link capacitor. The simulation results are validated through the DC link voltage and ultracapacitor voltage of prototype model of the system. The THD analyses for these three controllers were discussed and the AWPI with ultra-capacitor achieve a least value of THD than the other controllers. In this analysis, the AWPI controller reduces the peak overshoot value, the settling time to reach the final value and maintains the stability of the system. This distribution level interconnection concept of solar system is designed and simulated in MATLAB-Simulink for non-linear load. However, the experimental results of the wind and hybrid system using ultra-capacitor instead of Dc link capacitor is being carried- out as future work.

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