Performance analysis of Modified Second Order Adaptive Filter in Multilevel Inverter for Power Quality Enhancement

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***Abstract*— This paper deliberates a cascaded H-bridge Multilevel Inverter (MLI) topology, connected to load through Shunt-series switched (SSS) configuration for power quality enhancement. A Modified Second Order Adaptive Notch Filter (SOAF) is intended for reference current extraction that provides acceptable results in stable and distorted source situations. The phase shifted pulse width modulation produce switching signals with matching reference which delivers equivalent power among the modules. The suggested controller can accomplish substantial harmonic rejection even at unstable and disturbed supply voltage state. MLI is planned for compelling use of Distributed Energy Resources likewise to give ceaseless supply still on denied Power Quality circumstances. The SSS configuration is used for both current and voltage compensation. Therefore, MLI is fit for furnishing series and parallel arrangement with the grid and load using bidirectional switches. The Modified SOAF is actualized for multipurpose control, adaptivity to circumvent the loss appeared and for its improved disturbance elimination potential. The source current THD after compensation are observed to be with in the threshold as fixed by IEEE 519 standard. Thus the distributed micro grid system is able to provide constant, perfect and stable power supply and is confirmed by MATLAB simulation.**

Keywords- grid connected inverter, harmonic distortion, multifunctional converter, second order adaptive filter, power quality

I. INTRODUCTION

Modern environmental policies plus increased requirements of energy paved way to massive employment of renewable source utilizations. Consuming renewable energies however, is not always free of challenges. Major problems that arise due to integration of renewable energy sources (RES) to grid are voltage and frequency fluctuations, harmonics [1]. Several learning was made intended for unfailing combination plus proper positioning of the distributed supplies that concluded in micro grid introduction. These revisions primarily seeks on micro grid incidence forecast means, control design followed by the unquestionable branch, grid synchronization methods. The chief aim of such learning is to aid the micro grid as well as distributed supplies to travel in the course of the miniature disturbances in grid attached also islanded modes. Turbulence and unexpected alteration of micro grid end in voltage plus frequency wave distortions. These wave distortions might include unhelpful effects on power devices. As a result, the usage of a forceful plus unfailing controller and synchronizer is a necessity in micro grids [20].

Different control techniques have been introduced for efficient operation of grid connected inverter [18-20]. Variable compensation Control of power converters with low-voltage distorted power systems only improves current based PQ in single phase systems [2]. Capability of series and shunt active power filters depends a lot in grid inductance along with the position of compensator [3]. The study on such concern paved way for cascaded H-bridge multilevel inverter (CHBMLI). This provides effective interface of distributive energy resources and micro grids. It also acts as power quality conditioner and proved to be cost effective [24]. The problems related with these two dimension inverters that they work at higher exchanging recurrence which prompts higher exchanging misfortune and because of high DC-interface voltge the dv/dt worry over the switches are high. The power overseeing capacity of these inverters is low, so it's anything but a fitting decision for high power application, consequently restricted to low power applications [22]. Be that as it may, Multi-Level Inverter (MLI) works with lesser exchanging recurrence and the consonant end ability is very high contrasted with these two dimension inverters. So MLI's are desirable over work as a SAF and expand successful execution in high power applications [23]. So it has been normally perceived by analysts and industrialists. These MLI's discovers its application in PV networks, MV drives, APF's and FACTS.

Essentially three sorts of MLI are seen, which are fell MLI, nonpartisan point cinched and flying capacitor based. Be that as it may, the later two endures voltage adjusting and complex exchanging issue. In addition, among the distinctive topologies of staggered inverters, fell H-connect staggered inverter (CHBMLI) needs less components for producing a specific

voltage level, particular structure, delicate exchanging capacity and it doesn't require voltage adjusting capacitors. Subsequently it's an ideal exchange in medium-voltage extend control framework applications [25]. The measured structure of the CHBMLI empowers it to work with indistinguishable control system and amid blame in a module; a specific broken module can be substituted easily. Notwithstanding, the issue related with CHBMLI is it requires separate DC hotspot for every module. As the quantity of DC sources builds, it's control unpredictability load increments alongside high number of sensor prerequisites. In any case, mechanical application does not favor a high number of sensors to be incorporated in the framework. The dependability of the framework can be influenced because of individual control of number of DC sources and the general expense likewise increment. In any case, the previously mentioned issues can be successfully annihilated if CHBMLI works with a solitary DC source [26]. So in the present proposition a fell transformer is coupled to the yield of every module to create a staggered waveform and the fell association of transformer empower the CHBMLI to work with single DC source. For a viable utilization of a SAF, the control strategy must be appropriate to produce required remuneration current amid perfect and non-perfect condition. In the on-going past, numerous writings have been tended to concentrating on different techniques for reference current extraction for noteworthy consonant end [27].

Modeling of second order generalized integrator based PLL technique for converters show good performance but shows limited capability in rejecting grid disturbance and oscillatory errors in presence of DC offset and sub-harmonics [7]. The multipurpose control of grid connected inverter is achieved by using adaptive notch filter (ANF). It acts as frequency adaptive sequence components extractor. Also it performs multiple tasks and avoids the usage of PLL [8]. It suits best for grid synchronization, act as barrier to harmonics and other disturbances in grid signal also offers proficient detection of various components of grid signal [9]. Amongst various available synchronization procedures together with adaptive techniques, the modified second order adaptive filter (SOAF) is chosen for SSS configured MLI that possess high disturbance rejection capability. Modified SOAF removes essential component present in deformed grid signal during grid disturbances [10]. The proposal is given in favor of voltage plus frequency fixation in both grid conditions furthermore to make sure the power production adequacy. The quick and perfect synchronization procedure is chosen along with rapid reacting control structure Because of the various operation and advantages of adaptive filters it has many applications [11-17]. The modified SOAF supported micro grid system is designed using SIMULINK/MATLAB. The outcome illustrates the precision of the control method confirms balanced three phase voltages with constant frequency.

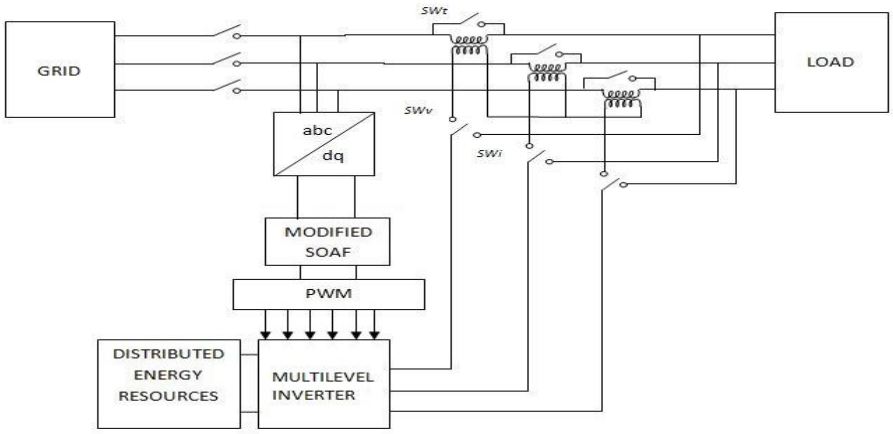

Fig. 1. The proposed system with shunt-series-switched MLI (SSS-MLI) with modified SOAF structure

II. PROPOSED MLI ORGANISATION

A 7-level adjusted CHBMLI is proposed by utilizing toroidal center transformer at the yield of every H-spans. The proposed transformer coupled MLI overwhelms the weakness of the conventional CHBMLI. The displayed topology utilizes a solitary DC-connect capacitor, in this manner limiting the quantity of sensors and controller for voltage adjusting. Alongside this, equivalent voltage is encouraged to every module which keeps away from unequal power dispersion among the modules. The additional element of fell transformers is galvanic confinement capacity and consonant decrease quality because of its spillage reactance, expanded unwavering quality of the framework and diminished electromagnetic obstruction issues. Additionally the inverter works at low exchanging recurrence. In the proposed work, a seven dimension voltage is created by associating three H-connect in each stage, whose yield is combined with single stage toroidal center transformer as appeared in Fig.2. Here every H-connect speaks to a module, guaranteeing alike setup and by associating transformers in each module, it empowers less demanding coupling to lattice incorporated frameworks and utility interfacing applications. Here every module develops voltages of +VDC, Zero, - VDC lastly all voltages are included, with the fell transformers, coming about a 7-level ventured waveform. Since the game plan conveys a 7-level yield voltage having three similar to modules, every module develop measure up to voltage which are included through the fell transformers. In CHBMLI, the yield voltage level created with the necessity of number of H-connect, can be spoken to as

$$V0 = 2n + 1$$

Here n demonstrates the per stage H-Bridge associated in the framework. So for a 7-level yield voltage, three H-spans are associated in each stage.

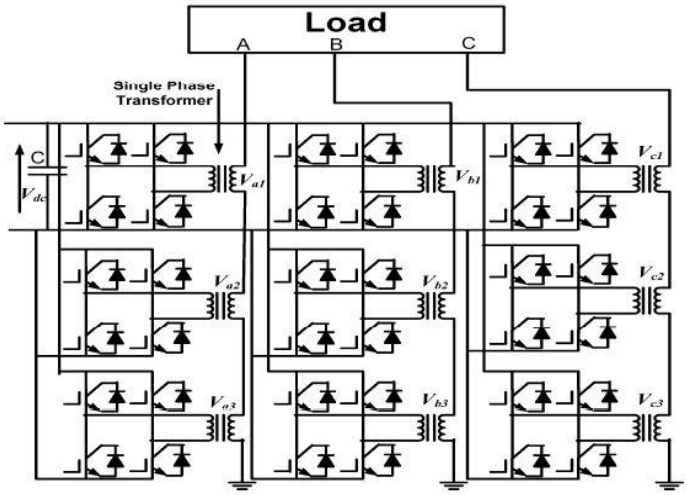

Fig. 2. The Cascaded H-Bridge MLI Structure.

III. SSS CONFIGURED MFGCI

A Shunt series switched (SSS) configured MLI is shown in Fig. 1. This novel SSS configuration is found to be effective in comparison with all other conventional grid connected inverter, as it is used to compensate various quality problems in any power grid by their different modes of operation. The system components are main power grid, distributed energy resource (DER), grid connected DC/AC converter, bidirectional switches followed by the load. The bidirectional switches that are used for SSS configuration in the MLI and their switching operation are responsible for the various operating modes and the corresponding compensation scheme [4].

TABLE I
SSS-MLI Modes and Functions

Mode	Configured	Switches			Functions
		SWt	***SWi***	***SWv***	
A	Shunt	On	On	Off	GCI
B	Shunt	On	On	Off	STATCOM
C	Series	Off	Off	On	DVR
D	shunt	off	On	Off	UPS

All the four operating modes and their respective functions of the SSS configured MLI is given in TABLE I. Mode A gives away the shunt configuration with switches *SWt* and *SWi* are closed, and *SWv* is at open condition. This clearly shows general grid connected inverter operation that provides AC output that supplies grid from given DC power at its input from distributed sources. Mode B shows similar shunt configuration along with similar switching as such as Mode A (switches *SWt* and *SWi* are closed, and *SWv* is at open condition), but operation of Mode B followed by Mode A operation functions as a STATCOM device. Thus Mode B offers mitigation of foremost Current based and trivial voltage based problems that affect the power quality. The Mode B offers two different operation that is, during power quality problems that are current based, it act as active power filter whereas during mitigation of power quality problem that are voltage based, it act as STATCOM (static synchronous compensator) despite the fact that it is still in parallel connection.

Mode C gives away the series configuration to grid with switches *SWt* and *SWi* are opened and *SWv* is closed. This operational mode of SSS-MLI mitigates severe power quality problems that are only voltage based. This function is achieved by application of voltage for compensation as per requirement, thus it act as dynamic voltage restorer (DVR). The additional functionality of the configured SSS scheme of given MLI during Mode D is the uninterruptible power supply (UPS) operation. That is the MLI is capable of providing demand power even after the disconnection of main grid from the load. During this operational mode, the MLI supplies required load demand as per requirement while the switch is opened [18]. Thus the performance proves the shunt series switched configuration of MLI is best suitable for micro grid applications, as it is able to mitigate power quality issues like overvoltage, under voltage, harmonics and maintains the nominal load voltage.

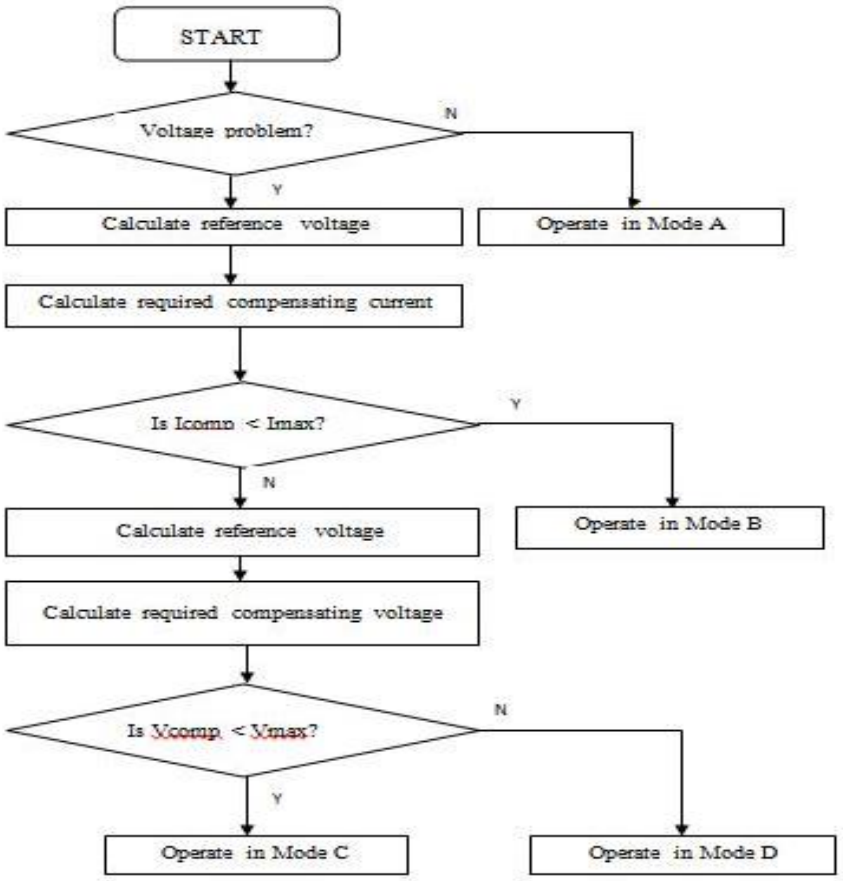

Fig.3. SSS-MLI mode transition flowchart.

IV. MODIFIED SECOND ORDER ADAPTIVE FILTER

In this paper the modified second order adaptive filter (SOAF) based synchronization method is implemented for extraction of harmonic components from the grid signals in grid connected distributed energy system. SOAF also aids in decrement of THD thus provide power quality enhancement which is affected by the presence of non-linear loads. The feedback signal for the proposed modified SOAF is the required frequency that is generated from the fundamental component extracted. Its behaviour and performance by the complete analysis proves to have high disturbance rejection capability in the system and very low settling time followed by satisfactory transient performance and hence found to be effective for fundamental component extraction in comparison with other grid synchronization techniques. The SOAF is modified so as to advance the computational time and for further reduction of total harmonic reduction and the focus of the modification is to suit it for the application of DER's with power grid along with power quality improvement.

A. Second-Order Adaptive Filter(SOAF)

In SOAF, the algorithm is adaptive where the reference for it is the essential frequency extracted with interest ω. The frequency that is extracted is actually two sinusoidal signals that is each ninety degree shifted. The combination of sine and cosine blocks is developed with least mean square algorithm that is put into operation as discrete forward integrators. Using SOAF the harmonic component is extracted with required frequency of interest by the use of determined essential positive sequence frequency of SRF-PLL. The conversion period of the SOAF is based upon the gain and the required essential element is achieved followed by the removal of harmonic part from the distorted waveform. The raise in bandwidth is achieved with enhance of gain thus reduces the settling time of the filter and its reduction is achieved by boosting the frequency. The exact data of essential frequency is acquired by the usage of SRF-PLL, in view of the fact that simply positive sequence essential part of impartial distorted grid waveform is introduce as its input.

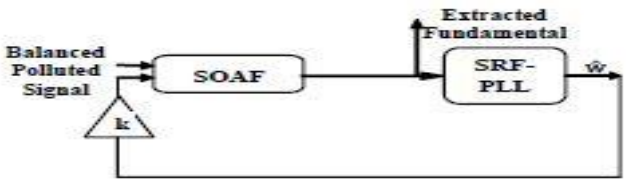

Fig. 4. Representation of conventional second order adaptive filter.

The most important harmonic components are of 5th and 7th orders in general for the period of non-linear load or grid fault. The total reduction of superior order harmonics is accomplished by appropriate choice of the bandwidth of SRF-PLL. The SOAF transfer function is given as,

$$\kappa = g_1 \varepsilon_v,$$

Where, g1= gain of error signal ε_v. The scheme consists of two transfer functions of second order namely adaptive band pass filer (ABPF) and adaptive notch filter (ANF). Damping factor and settling time (for fundamental) is given as,

$$\zeta_1 = g_1/2\hat{\omega}\,;\; T_{s1} = 9.2/g_1$$

Thus the observations on SOAF filter shows that enhancement of gain results in rise of bandwidth of filter which provides the advantage of settling time reduction conversely the system stability is affected thus proves that this system is not the satisfactory selection for grid system which has inconsistent frequency conditions.

B. Modified Second-Order Adaptive Filter(Modified-SOAF)

The chief negative aspect of any power grid system is that only for the period of balanced and undistorted operating conditions, the grid signal parameters have their sinusoidal waveform of essential component. But the grid signal turns out to be unbalanced or include distortions with occurrence of harmonics all through faulty conditions and by reason of the non-linear load. During such deformed grid signals or frequency deviations the SOAF function fails. Thus a novel means of conversion of second order adaptive filter is proposed in this section to overcome the difficulty mentioned above. Through this alteration, the SOAF performance was prepared to be autonomous of the frequency of the system. As the advancement of this alteration the SOAF will be found trouble free to dig out the fundamental element from the affected signal that is applied as the reference for the PLL block. The alteration made in the conventional SOAF is multiplication of the frequency to be filtered $\hat{\omega}$ with $g3\epsilon v$. From the above said conversions the conventional SOAF was made best suitable for applications of micro grid with DER integration without disturbing the stability of the system. Intended for the over said compensation come to pass, the subsequent alterations have been done.

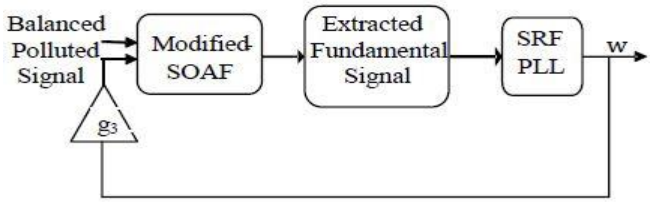

Fig. 5. Representation of modified second order adaptive filter.

Whose transfer function was modified as,

$$k = g_3 \hat{\omega} \epsilon_v$$

The transfer function of input to output is adaptive band pass filter and the transfer function of input to error is a notch filter.

$$ABPF_1(\Sigma) = AF_1(\Sigma)/1 + AF_1(\Sigma);\; ANF_1(\Sigma) = 1 - ABPF_1(\Sigma)$$

Resolving period of the proposed second-order system is calculated as, $T_{s1} = 4.6\tau_1$, here τ_1 is the time constant. The damping factor, fundamental time constant, settling time for given modified-SOAF is calculated from the below equation,

$$\zeta_1 = g_3/2;\;\; \tau_1 = 2/g_3\hat{\omega};\;\; T_{s1} = 9.2/g_3\hat{\omega}$$

From reference it is clear that the modified-SOAF reaction is quicker in times of high gain values which are used for the estimation of the proposed SOAF bandwidth. Even at small gain values, the capability of filtering is found to be more than satisfactory however it takes relatively high settling period. Accordingly, conciliation has to be done among the gain rate as well as bandwidth of the proposed SOAF on the way to obtain the finest outcome. Subsequently it proves that bandwidth is solitarily based upon gain ($g3$) besides just like the conventional filter it is no more a function of frequency and gain, this turns it to be suitable in favour of the implementation for variable-frequency power systems.

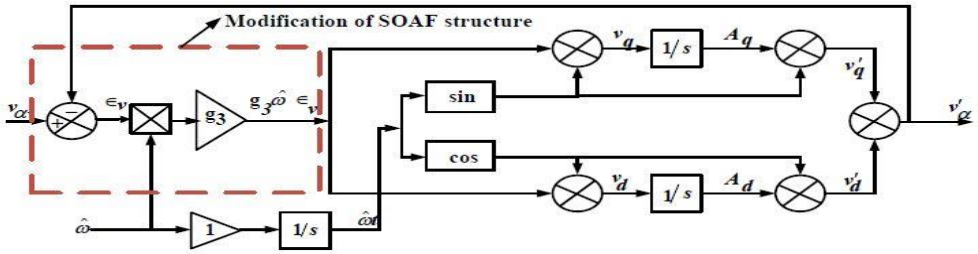

Fig. 6. Block diagram of modified second order adaptive filter.

V. SIMULATION RESULTS

The control scheme with suggested SSS-MLI is validated with MATLAB Simulink. Voltage quality issue on grid voltage is justified here. The simulation of the proposed SSS-MLI is done to check the performance. The compensated PCC voltage reference is brought into line for pre-fault voltage. The MLI real power supplies grid and the load. Grid supplies the reactive power for load. In Mode B, the compensating current is injected. Voltage regulation is done by negative sequence current of SSS-MLI. However, complete compensation at PCC is not achieved and grid current is unbalanced. That is, the real and reactive power of SSS-MLI is oscillating because of the negative sequence current. For this, the reference voltage must be aligned to achieve zero averaged active power. Thus the required positive and negative sequence voltage is injected during Mode C of SSS-MLI and mitigates the voltage quality problem that has not been solved and PCC voltage is regulated. As a result, with less reactive power consumed both grid and load voltage are sinusoidal and balanced.

However, the frequency response analysis demonstrates that filtering performance is better with low gain value and damping factor but the dynamic response is slower. Following this, the gain must be less than 0.5 for required filtering capability and dynamic performance. So the implementation of modified-SOAF filter is found to be the perfect choice for effective operation and for achieving low total harmonic distortion. The simulation results for such a system with SSS-MLI and SOAF is shown below. The output shows the intentional voltage disturbance between time period of 0-1 and 1.5-2 at grid voltage even for which the output load voltage is undisturbed sinusoidal and balanced thus the THD at load side reduces.

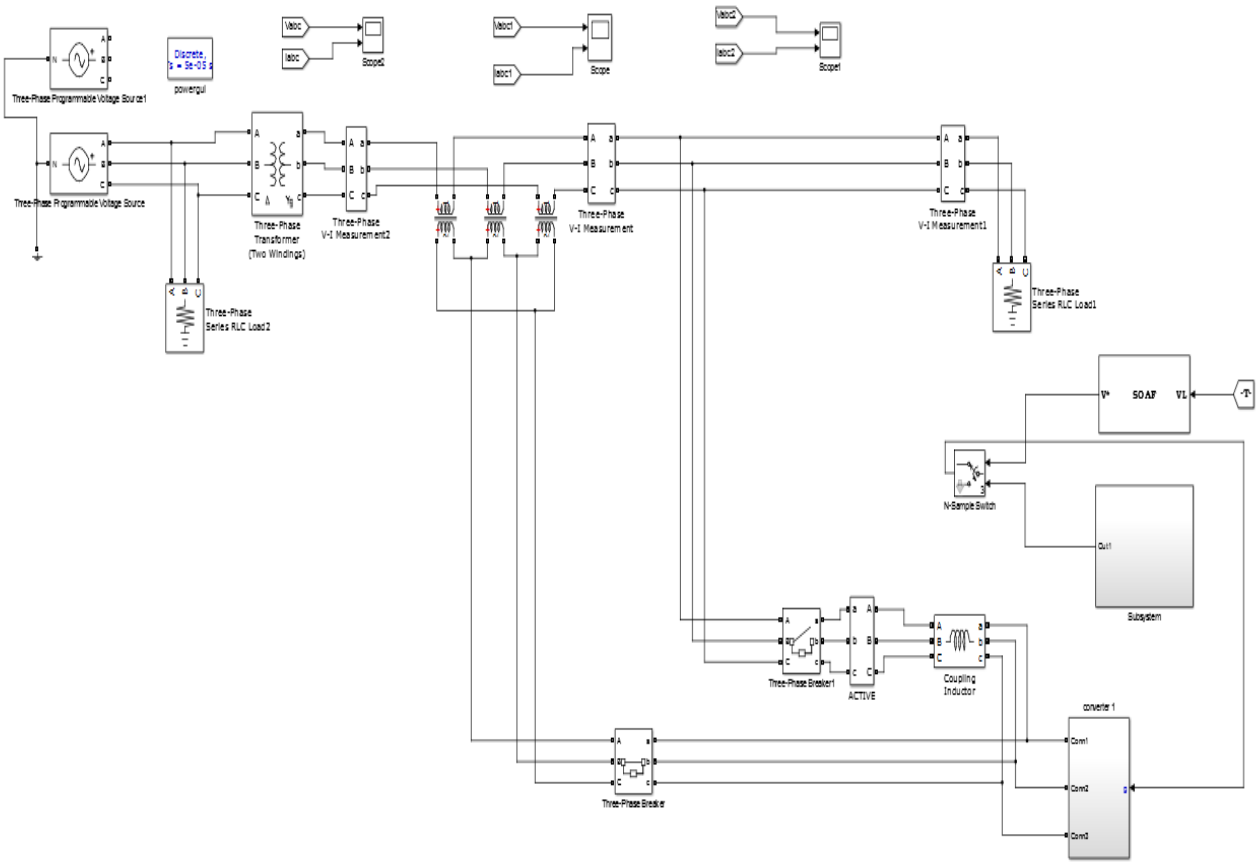

Fig. 7. Simulation circuit diagram.

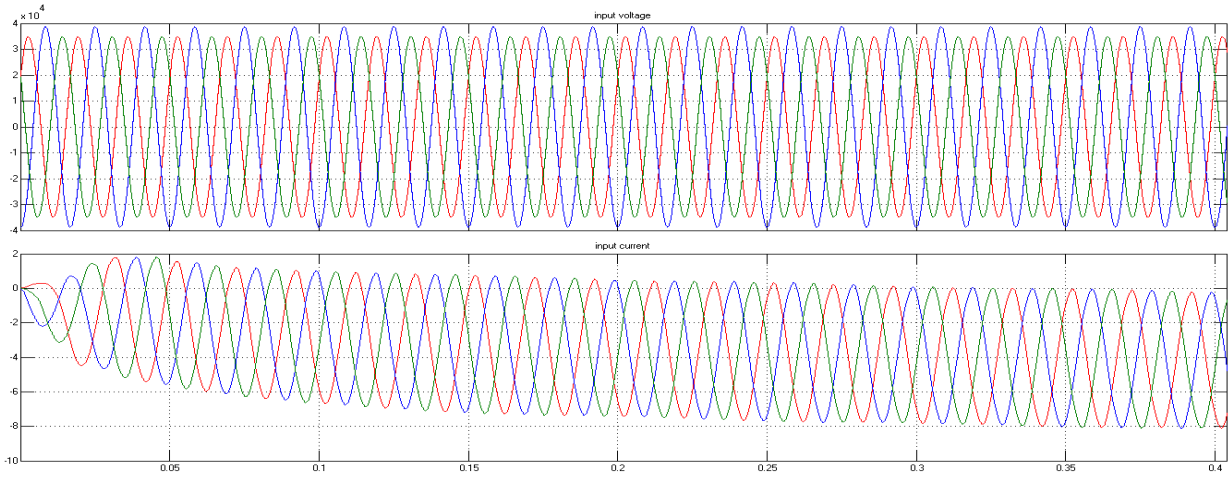

Fig. 8. Input waveform of proposed system.

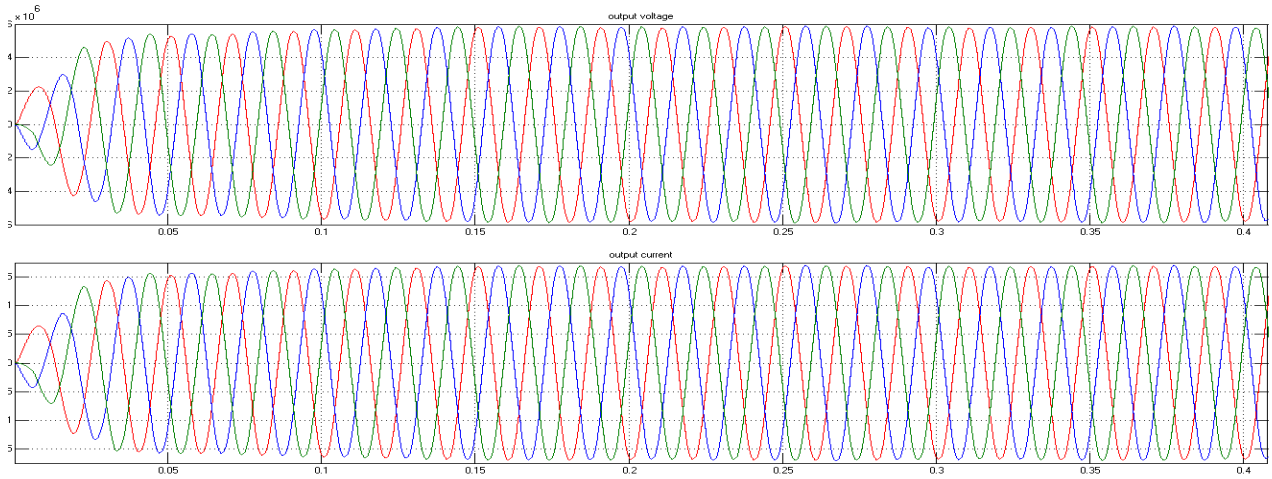

Fig. 9. Output waveform of proposed system.

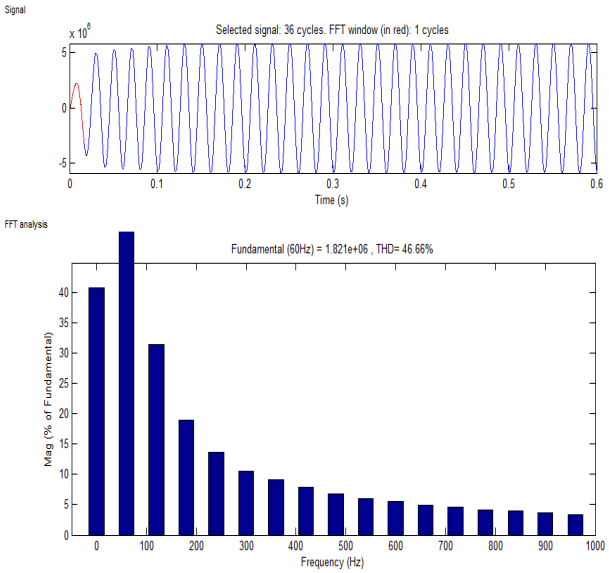

Fig. 10. Existing system harmonic distortion

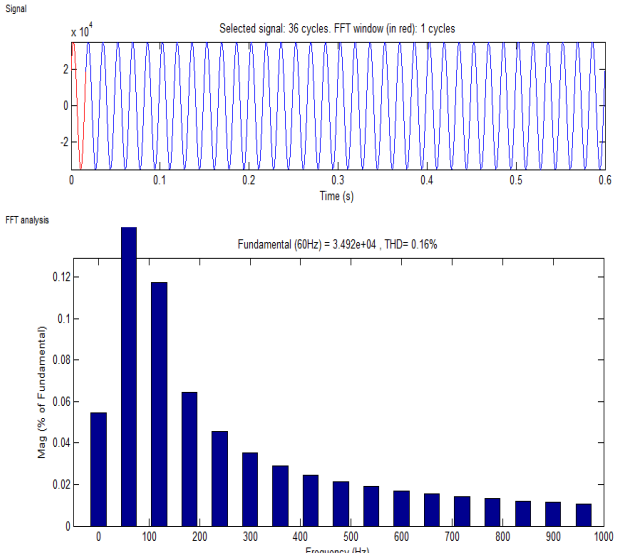

Fig.11. Proposed system harmonic distortion

VI. CONCLUSION

Inverters in distribution systems with misshaped grid voltage certainly produce elevated amounts of current harmonics. In MG the voltage and frequency oscillations happen because of accidental changes and disturbances which have critical effect. A cascaded transformer coupled multilevel inverter that act as a shunt active filter and provides harmonic lessening during various supply fundamental condition is suggested. The modules receive similar power among the inverter modules using single DC-link capacitor operation. The total design of created topology was explained alongside its control operation. For current harmonic extraction an SOAF centred controller is connected to separate the essential burden current that aids in assessing the reference current. The switching signals are produced with the phase shifted PWM technique by relating the reference. At last the introduced control procedure connected to the created topology of MLI adaptively mitigates harmonic currents without compromising stability even when the grid is extremely weak and purely reactive and is verified by simulation.

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