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Introduction

Historically, the technology of the DC to AC power conversion evolved from the late 19^{th} century through middle of the 20^{th} century with the invention of the electro-mechanical energy converters such as the rotary converters or motor-generator systems. This technology supported the DC-AC or AC-DC power conversions in the pre-power electronics era. The rotating machines used for the purpose were quite heavy, noisy and less-efficient. The early 20^{th} century witnessed different alternatives for the power conversion using the Power Electronics (PE). The classical era of power electronics began when an American scientist Hewitt, while performing an experiment on the vapor mercury arc lamp, found that the current was flowing in one direction only i.e. from anode to cathode of arc lamp. This was a rectification operation achieved through the mercury arc lamp that followed to the invention of glass-bulb pool-cathode mercury arc rectifier in 1920. Gradually, Thyratron and Ignitron were developed in 1923 and 1931 respectively. However, the popularity of these devices ended within few decades around 1950s. The cause of this early drop in the popularity of vacuum tube rectifiers was due to the beginning of the modern era of the power electronics with the birth of silicon transistor at the Bell Telephone Laboratories in 1948. The evolution of silicon based power electronics technology had a breakthrough invention in 1956 with the introduction of the static devices namely thyristors. The thyristors then commercialized by the General Electric Company in 1958. The thyristor technology succeeded in capturing the electrical energy market and created its monopoly for almost next 25 years from its invention due to the lack of competitive technologies. However, the challenge of the Turn-OFF process of thyristors along with the requirement of new devices having faster switching capability, high current and voltage ratings and ease in control encouraged other technologies. In 1970, the bipolar junction transistor (BJT) was invented for the low/medium power and frequency applications. The BJTs could not maintain their applicability at large and for a long period due to the invention of the metal-oxide semiconductor field effect transistor (MOSFET) in 1978. The MOSFET has a wide applicability in various high frequency and low power applications. In 1983, the insulated-gate bipolar transistor (IGBT) was developed through the amalgamation of the intrinsic properties of the BJT and MOSFET. The IGBT possess the merits of BJT and MOSFET in a compact design. Though the MOSFET and IGBT are popular recent technologies, the thryristors are also used in several power applications. A derivative of the conventional thyristor i.e integrated gate commuted thyristor (IGCT) developed in 1997 is used in medium to high power applications. Moreover, in recent times, a variety of the high power, wide band-gap and high frequency solid-state power switches are available in a very compact design for variable voltage and/or frequency power applications.

The static devices have a wide applications in the different fields of the power technology such as automation and control, electrical drives, signal-processing and renewable energy (RE) applications. Out of these applications, the renewable or alternative energy based power systems have encouraged and welcome worldwide to support conventional power systems and to alleviate the consequences of the extensive exploitation of the conventional energy resources. Recent decades have witnessed a significant paradigm shift in the conventional power systems to renewable energy based power systems. A perennial development in the advance power electronics (applications of the solid-state devices) and control strategies have largely encouraged and widen the scope of the small/medium local power systems supported fully or partly by RE sources such as microgrid, residential power system, distributed generation systems. Philosophically, the power electronics is the nervous system of the today's power systems while the control is the brain of the smart power system; these two components complement each other. In a typical power system, the power electronics devices transform the electrical energy and the control directs the transformation of this energy in a desired way. This is carried-out through the power converters.

Power converters are one of the integral entities in the local power systems. These are the intermediate links to connect the sources, loads and storage devices in a typical power system. The application of the renewable/alternative energy sources such as solar-PV, fuel-cell in the low/medium power systems is one of the emerging research fields. The output of some of the renewable/alternative energy sources is DC in nature. Furthermore, the battery bank is used as electrical energy storage (EES) system to cope with the short-time energy deficit in such typical power systems. Consequently, at the consumer-end, the amount of the DC loads are growing with the persistent development in the DC power technologies and the emerging research interest in the renewable energy applications. However, the AC loads are pervasive due to the several factors related to the ease of availability, advanced safety measures, cost-effectiveness and matured AC power technologies. To supply the AC loads, the DC to AC power converters or inverters are required. Moreover, the static synchronous generators (static-SGs) or synchronverters [Ferreira *et al.*, 2016; Xiong *et al.*, 2016; Zhong and Weiss, 2011] are the emerging static energy conversion technology based on the working principle of the conventional SGs to harvest energy from the RE sources. Unlike conventional SGs, the static-SG requires the DC-AC power converter along with a control strategy based on the theory of the SG to mimic a conventional SG. The DC-AC converters are also used at the point of common coupling (PCC) in the grid-connected power applications [Kjaer *et al.*, 2005]. In grid-connected systems, the DC-AC power converters exchange power between the DC power systems such as microgrid and the conventional grid or main grid. Therefore, the DC-AC power converters are imperative in the power systems.

In the low power-applications (up to 5 kVA), the single-phase PWM power converter are generally used [Serban, 2015]. In the literature, several topologies of the single-phase DC to AC power converters, for example, single-stage DC-AC converters, multi-stage DC-AC converters (buck-derived, boost-derived, buck-boost derived or bidirectional buck-boost), impedance source inverters (ZSI, q-ZSI, q-SBI), multilevel converters are extensively explored for the different power applications. For an ideal inverter or DC-AC converter, the instantaneous values of the input power and output power must be equal. However, in actual scenario, there is the power mismatch between the instantaneous DC power and instantaneous AC power. The pulsating nature of AC output power causes the pulsation in the average DC input power. The pulsation at the DC input are two times of the supply or line frequency. Therefore, the DC-AC power converters supply to AC loads with the unwanted reflection of the Second-order Harmonic Current (SHC) ripple (decoupling ripple or $2\omega-$ripple or two-times line frequency ripple) at the DC input. For instance, suppose an inverter supplies an AC load at the angular frequency ω rad/sec, the pulsation at the DC input will at 2ω rad/sec. Generally, the problem of the second-order harmonic ripple is dominant in the single-phase DC-AC converters. In case of the three-phase DC-AC power converters, this problem is only significant at the unbalanced-load condition. In the single-stage DC-AC converter, this ripple at the DC link propagates towards the DC source and inject directly into the DC source if the DC link capacitance is low or no compensation technique is used. A mathematical representation of the cause for $2\omega-$power ripple in the average DC input power of the single-phase inverter is as follows,

$$\begin{aligned} v_{ac} &= V_{max}cos(\omega t) && \text{(1.1a)} \\ i_{ac} &= I_{max}cos(\omega t-\theta) && \text{(1.1b)} \\ v_{ac}i_{ac} &= 0.5V_{max}I_{max}cos\theta+\underline{0.5V_{max}I_{max}cos(2\omega t-\theta)} && \text{(1.1c)} \\ p_{ac} &= P_o+\underline{p_{ripple}} && \text{(1.1d)} \end{aligned}$$

Here v_{ac} and i_{ac} are the instantaneous output AC voltage and output AC current of the inverter. The angle θ is the displacement angle; *max* stands for the maximum value of v_{ac}/i_{ac}. The underline part of (1.1) is the second-order harmonic power ripple (decoupling power ripple) pulsating over the average DC offset. In the Fig. 1.1, this phenomenon of $2\omega-$ripple reflection at the DC input and its propagation towards DC source is depicted. In Fig. 1.1, P_o and p_{ripple} are the average DC power and $2\omega-$ power ripple components pulsating over the P_o respectively. A general practice to avoid the injection of ripple into the DC source by using a large size aluminum electrolytic capacitor (E-cap) at the DC-link. However, the E-caps are vulnerable to low-frequency ripple due to low ripple handling capability and high parasitic resistance. The ripple causes i^2r-heating losses inside the electrolytic capacitors [Stevens *et al.*, 2002; Wang and Blaabjerg, 2014]. The life-span of an E-cap is $1000-7000$ hours at 105^o C [Almeida *et al.*, 2015] which is quite shorter than the life of a solar PV panel (25 years approx.) in a PV system [Dunlop *et al.*, 2005]. This raises an important question on the reliability of the complete system. A study conducted using data of 213 failure cases from 103 grid-tied solar PV systems at the Florida solar energy suggests that the 139 failures are due to the inverter failure [Petrone *et al.*, 2008]. According to [Wolfgang *et al.*, 2007], in the power converters, 51% instances of the inverter's failure are due to the solid-state devices and aluminum electrolytic capacitors. Moreover, 21% failure instances out of 51% are due to the aluminum capacitor failures only. The use of E-cap increases the size, cost and weight of the system as well. The thin film capacitor is a reliable alternative to replace the E-cap. The low ESR value and large ripple handling capability of thin-film capacitor make it a suitable choice. However, an equivalent size of thin-film capacitor is required in the place of the E-cap. The high cost of the thin film capacitor makes it difficult choice [Bramoulle, 1998]. The use of thin-film capacitor is suitable and preferred in the active power decoupling circuits or control-oriented power decoupling techniques; a comparatively small size film capacitor is required in the active filter [Zhong *et al.*, 2017].

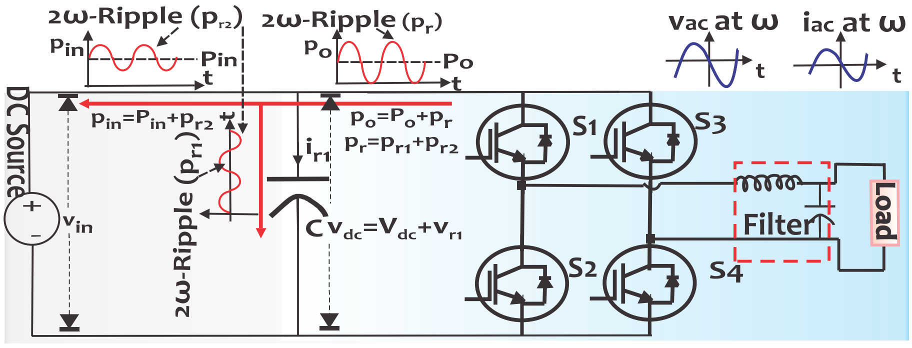

Figure 1.1 : Background of $2\omega-$ripple: reflection, propagation and injection

In the next Chapter several power decoupling techniques based on passive power decoupling techniques (PPTs), active power-decoupling techniques (APTs) and control-oriented compensation techniques (CCTs) for two-stage converters or DC-AC converters with front-end control circuits are reviewed in depth from the existing literature. The PPTs utilizes passive components (L,C) for the power decoupling. Use of the E-cap is most simple and conventional technique. Other than the cost, size and weight of the E-cap, the reliability of the E-cap is the major concern. Even though the film-capacitor minimizes the reliability problem, it adds to the cost, weight and size to the system in the same proportion. The film capacitor combined with controlled-power-electronics circuits gives the one of the best possible solutions to eliminate the E-cap and therefore, recent times have witnessed in a persistent evolution in the active decoupling techniques. A comparatively small film capacitor is used in the APTs. The APTs can be applied to the DC-side and AC-side or mixed-type applications. The DC-side application of the APTs is easy and does not affect the H-bridge circuit. However, the control scheme should be designed accordingly based on the power to be decoupled by the film capacitor, required peak voltage and peak current handling capability of the film capacitor, and the phase difference between the instantaneous values of the voltage of the film capacitor and output AC voltage. The basic control approach is to balance the decoupling power at the DC-link by the power exchange with the film capacitor. The AC side APTs are comparatively better on the basis of the efficiency of the system due to power decoupling at the AC side itself. However, the application of these techniques interfere the main H-bridge circuit. This causes modification in the modulation index of the inverter. This may lead to the under-utilization of the power-electronics devices and increased stress on the system components and the control is also a challenge. In both the cases DC side and AC-side applications of the APTs, the number of the components increases. This reduces the overall efficiency of the system and increases the size, cost and complexity of the control method. The two-stage DC-DC-AC converters or the converters with front-end buck or boost operation capability have inbuilt option of the active control. The front-end DC-DC converter can be utilized for purpose of the input SHC ripple-mitigation. The control-oriented compensation techniques (CCTs) are generally utilized in such systems. The dual-loop control scheme and output-impedance shaping scheme are two popular CCTs. The former scheme aims to minimize the SHC ripple in the reference current of the inner-loop in order to compensate the SHC ripple in the input current. The later scheme aims to increase the output impedance of the front-end converter such that the SHC ripple is forced to flow through the DC-link capacitor branch. However, both the schemes suffer the poor dynamic performance. The addition of resonant filter in the current or voltage loop has shown improved dynamic performance. However, this limits the bandwidth of the system and therefore affects the dynamic performance of the system. A poor-design of the resonant filter may induce instability. Only a few techniques, partially, address the problem using linear controllers. These controllers ensure ripple mitigation but degrades the dynamics performance, and ensure stability about the operating points only. Uncertain working characteristics of DGs and presence of substantial ripple in the system may lead to nuisance tripping of protection circuits. Furthermore, a large variation in line and load may result into substantial oscillations. This may induce instability to the system with the linear controller. Controller needs to consider ripple mitigation and system performance together. Therefore, there is a need of techniques which mitigate the effect of ripple without compromising the dynamic performance and has sufficient robustness with respect to uncertainty.

The nonlinear control approaches are generally preferred in the system with the large line-load disturbances. The RE based systems are prone to such disturbances. Furthermore, renewable/alternate energy sources are vulnerable to low-frequency $2\omega-$ripple, for instance, fuel starvation and heating occur in fuel cell, MPPT operation is affected in the solar PV and fuel-cell based systems. Moreover, the frequent large line and load transients pose a challenge on the reliable and desired operation of the system. Therefore, the non-linear control approaches may be tried-out in such applications. The nonlinear control approaches perform well at the large line-load transients in comparison to the linear controllers. The nonlinear controls such as sliding mode control (SMC) and integral sliding mode control (ISMC) ensure robustness against the matched uncertainty. Therefore, there is a need to explore the nonlinear control approaches thoroughly in the context of the mitigation of $2\omega-$ripple problem along with required dynamic performance in the single-phase inverters.

In this work, the adaptive sliding mode control and integral sliding mode control are proposed to mitigate the SHC ripple problem along with improved dynamic performance in the two-stage DC-DC-AC converter and quasi-switched boost inverter. The basic principle of SMC and ISMC is discussed in following Sections respectively.

1.1 PRINCIPLE OF SMC CONTROL

The sliding mode control is well known for its important feature of insensitivity to disturbances and parametric variations [Utkin and Shi, 1996]. Due to this feature, the SMC control approach has been receiving a good response from the control community since 70s.

There are two important steps to design SMC viz. (a) the first step is to design a switching function, σ which is a stable sliding surface for $\sigma = 0$ and the corresponding system motion when $\sigma = 0$ is known as sliding mode (b) second step is to design a control law that induces the sliding mode in finite time. In the SMC approach, initially the system states are forced towards the sliding surface from the initial condition. This phase is known as the reaching-phase. The next phase is attributed as sliding mode. In this phase, the system states converge to operating point for a stable sliding surface. A continuous attraction and steering of system states from the initial condition towards the sliding surface ensure that the sliding mode exists, for this to happen the existence condition, given by (1.2) must hold,

$$\sigma\dot{\sigma} \leq -\eta|\sigma| \tag{1.2}$$

Here, η is a positive number.

For the convergence of the system states to the operating point, the sliding mode must be stable. For this, the Lyapunov stability is one of the approaches to investigate the stability of the sliding surface. To know more details, readers are encouraged to read excellent text on the subject [Edwards and Spurgeon, 1998; Utkin, 1978]. It is noted that during reaching-phase, the system dynamics are sensitive to the disturbance and parameter variations. However, the sliding mode is insensitive to the matched uncertainty or disturbances in the system. The principle of SMC is depicted in Fig. 1.2.

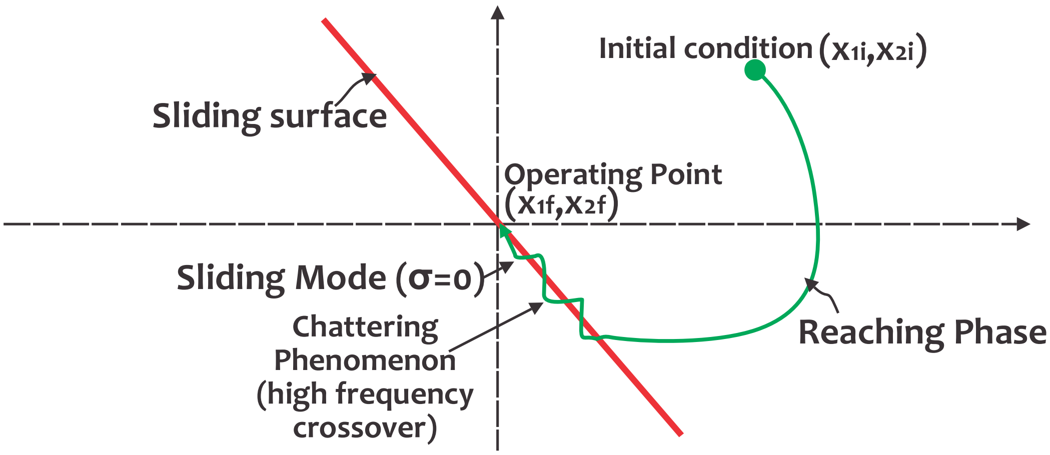

Figure 1.2 : Principle of SMC

In the next Section, the basic principle of integral sliding mode (ISM) control is discussed.

1.2 PRINCIPLE OF ISM CONTROL

The basic principle of the ISM control is depicted in Fig. 1.3 [Bandyopadhyay *et al.*, 2009; Utkin and Shi, 1996]. The important feature of the ISM control is, it allows SMC to combine with a nominal controller e.g. classical controller such as PI controller, LQR. The system dynamics are governed by nominal controller. However, nominal controller, generally, does not eliminate the uncertainty/disturbances in the system. The ISM based controller, which is added to the nominal controller, eliminates the matched uncertainty/disturbances from the very beginning of the system response [Rubagotti *et al.*, 2011]. Therefore, the overall performance of the system improves. The overall control input is obtained by combining the control inputs of nominal controller and ISM controller.

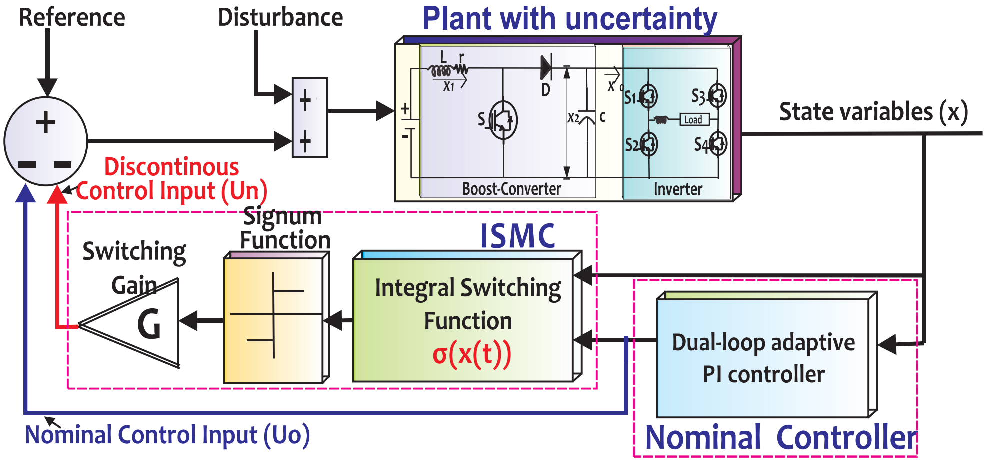

Figure 1.3 : Principle of ISM control

Suppose the dynamic model of a system with uncertainty,

$$\dot{x} = Ax + Bu + \varphi_m \tag{1.3}$$

Here x is the state-vector, A is the system matrix, B is the input matrix, φ_m is the matched uncertainty. $A \in \mathbb{R}^{\mathrm{nxn}}$ and $B \in \mathbb{R}^{\mathrm{nxm}}$. Assume all states are known, rank(B)=m, pair (A, B) are controllable and the maximum upper bound of φ_m is known, say ρ. Considering this, $\varphi_m = \rho h$. Here h represents a type of the disturbance with unit magnitude. $\rho \in \mathbb{R}^{\mathrm{nxl}}$ and lies in the range space of B. Therefore, for some matrix V, $\rho = BV$ where $V \in \mathbb{R}^{\mathrm{mxl}}$. Therefore, (1.3) can be written as,

$$\dot{x} = Ax + Bu + BVh \tag{1.4}$$

Suppose σ is the switching function (see Fig. 1.3) given by,

$$\sigma = Gx \tag{1.5}$$

Here G is the matrix to be designed such that $GB \neq 0$ where $G \in \mathbb{R}^{\mathrm{mxn}}$. Sliding mode should be stable and ensure robustness towards the uncertainty. For this, consider derivative of σ as,

$$\dot{\sigma} = G\dot{x} \tag{1.6}$$

Using (1.4) and (1.6),

$$\dot{\sigma} = GAx + GBu + GBVh \tag{1.7}$$

Suppose the sliding mode exists in finite time. This implies $\dot{\sigma} = 0$. Solving this for u gives equivalent control as follow,

$$u_{eqv} = -(GB)^{-1}(GAx + GBVh) \tag{1.8}$$

Using (1.8) in (1.4),

$$\dot{x} = KAx + KBVh \tag{1.9}$$

Here projection operator, $K = (I - B(GB)^{-1}G)$ where I is identity matrix of order n. It is noted K has a property of $KB = 0$. This implies, in the closed-loop system given by (1.9), the matched uncertainty is eliminated. The closed-loop system reduces to $\dot{x} = KAx$. This proves that the sliding mode inherits the property of invariance against matched uncertainty. The next important task is to choose an integral switching function that ensures sliding mode from the very beginning of the system response. In order to ensure invariance towards matched uncertainty from the beginning of the system response one can choose integral switching function [Castanos and Fridman, 2006; Utkin and Shi, 1996],

$$\sigma(x(t)) = G[x(t) - x(0) - \int_0^t \{f(x(\tau)) + Bu_o(x(\tau))\}\, d\tau] \tag{1.10}$$

Here u_0 is nominal control input and one of the choices of discontinuous control (u_n) is,

$$u_n = -\eta(GB)^{-1} sign(\sigma) \tag{1.11}$$

To induce sliding mode $\eta > \rho$. The total control input is,

$$u = u_o + u_n \tag{1.12}$$

1.3 MOTIVATION AND RESEARCH OBJECTIVES

Recently, several control techniques are researched to mitigate $2\omega-$ripple problem in the single-phase inverters. The passive power-decoupling techniques are conventional and simple ripple compensation techniques which utilize the electrolytic capacitor or inductor or combination of the passive energy storage components. Active power-decoupling technique is an alternative for the passive power-decoupling techniques and it possess several benefits over the passive power decoupling techniques. However, the active power-decoupling techniques add extra circuitry to the system. In the two-stage DC-DC-AC converter and DC-AC converter with the front-end control capability such as quasi-switched boost inverters have in-built option to control the $2\omega-$ripple through the front-end converter or circuit. The linear control techniques are largely explored in such systems to mitigate the SHC ripple problem without adding extra circuitry to the system. The linear control techniques mitigate the SHC ripple problem at the input, however, these control compromise among the dynamic performance, robustness and stability at the large line-load transients. Nonlinear control techniques are preferred in the systems where the large line-load transients are frequent. Moreover, nonlinear control such as sliding mode control and integral sliding mode control ensure robustness against the disturbances/uncertainty. Therefore, there is a need of the nonlinear control techniques which minimize the SHC ripple problem and ensure stability at the large line-load transients along with robustness against the disturbances/uncertainty. This is the motivation of the work done in this Thesis.

The main objective of this research work is to mitigate the SHC ripple or $2\omega-$ripple problem in the single-phase inverter with improved line-load transients performance through the proposed nonlinear sliding mode surfaces. In this Thesis, new sliding mode controller and ISM based controller are discussed to mitigate the SHC ripple problem in the two-stage DC-DC-AC converter and quasi-switched boost inverter. The techniques used in this work for the ripple-reduction at the input are based on the output-impedance shaping through the proposed adaptive sliding mode control and the adaptive control of the bandwidth of voltage-loop in the dual-loop control through the proposed adaptive PI controller (as nominal control) in the integral sliding mode control. The adaptive nature of the proposed controllers achieves the ripple mitigation at the input and improve dynamic performance of the system at the large line-load transients simultaneously. The controllers are verified through a detailed experimentation and simulation studies. A comprehensive review of the second-order harmonic ripple problem in the single-phase inverter is carried-out. A study on the DC microgrid having multiple inverter loads is carried-out in the context of the second-order ripple problem. To minimize the $2\omega-$ripple at the DC bus, a phase-adjustment control technique for the two inverter loads connected at the DC bus in a typical DC microgrid is presented with the simulation results. Here is the brief of the contributory work in the Thesis,

In the First work, the proposed technique implements an adaptive sliding mode controller for the two-stage boost-derived DC-DC-AC converter. The basic concept of the ripple reduction and improvement in system dynamics is based on the shaping of the output-impedance. The proposed controller modifies the output impedance of the front-end DC-DC converter such that the propagation of SHC ripple is resisted in the direction of the DC source and hence protect the source from adverse effects of the SHC ripple. The proposed controller minimizes the SHC ripple at the input and keeps its peak to peak value within 1% with respect to average input current value. The adaptive nature of the proposed controller improves the dynamic performance. At the load transients from no-load to full-load and vice-versa, the undershoot/overshoot in the DC link voltage with respect to the reference voltage are -8% / $+3\%$. The negligible undershoot and overshoot in the DC-link voltage were observed at the line-transients.

The two-stage DC-DC-AC converters are popular in several power applications. In such converters, the front-end DC-DC converter regulates the DC-link voltage and the power required by the load in the presence of the uncertain line-load disturbances. The back-end DC-AC converter is the voltage source inverter (VSI). The voltage source inverter may suffer an undesired switching of the switches in the same leg(s) of the VSI that follows the short-circuiting of charged capacitor at the DC-link through the leg(s) and hence causes damage to the system. The impedance source inverter is one of the alternative for such converter. The impedance source inverters withstand without any damage to the system when the short-circuiting of the charged capacitor happens through the leg(s) of inverter. Moreover, the short-circuiting is used to boost the input voltage; this mode of operation is known as shoot-through mode. Therefore, an addition front-end DC-DC converter is not required to boost the input voltage. The quasi-switched boost inverter is one of the converters from the impedance source inverter family. The quasi-switched boost inverter has high voltage boost-gain with the shoot-through operation capability.

In the Second work, a quasi-switched boost inverter (q-SBI) is considered. The q-SBI is capable of the shoot-through operation. A modified version of the controller as proposed in the first work is implemented with quasi-switched boost inverter. The concept of the SHC ripple mitigation is based on the output impedance shaping. The SHC ripple in the input current of q-SBI is less than 5%. The undershoot and overshoot are less than 18.5% of the reference DC-link voltage at the load transients and negligible at the line transients. The size of the capacitor and inductor required are smaller in comparison to the existing work in the literature.

The classical control methodologies such as PID, optimal control are largely researched for the mitigation of SHC ripple in the two-stage DC-DC-AC converters. However, such control methodologies ensure stability close to the operating point only. Moreover, in practical applications, the disturbances and uncertainty are involved which disturb the desired operation of the linear controllers. The nonlinear controls e.g. SMC are generally preferred to ensure the robustness against the disturbances/uncertainty and the stability at the large line-load transients. To avail the advantages of classical and modern control methods, there is a need of control methodologies which mitigate the SHC ripple problem along with desired dynamic performance and ensure stability and robustness. The integral sliding mode control is one of the desired control approaches. The integral sliding mode control (ISMC) ensures the robustness against the disturbances/uncertainty from the beginning of the system response and allows the classical control methodologies to combine with the sliding mode control.

In the Third work, a new control technique is proposed based on the integral sliding mode control for the mitigation of the SHC ripple problem at input of the boost-derived DC-DC-AC converter. An adaptive PI-controller (nominal controller) amalgamates with SMC. The proposed ISM based controller mitigates SHC ripple problem, improve the system dynamics and add invariance property to the system. The nominal controller reduces the SHC ripple in the input current and keep its value less than 7.7%. However, a 50% (approx) reduction in the size of the system parameters (inductance, L and capacitance, C) increases the ripple to 15% (without ISM controller). With the proposed ISM based controller, the ripple reduces to a negligible value. Furthermore, the proposed controller eliminates the effect of the disturbances entering through the control input. In the experimentation, the performance of ISM based controller in the elimination of the disturbances entering through the input channel is validated.

In the Fourth contribution, firstly, a study on the second-order ripple is carried-out for a typical DC microgrid having multiple inverter loads. Secondly, a phase-adjustment control technique is proposed for the ripple mitigation at the DC bus that supplies two inverter loads. The basic concept is to control the required phase difference between the output voltages of the inverters such that $2\omega-$ripple reflected at the DC-bus by the first inverter is canceled by $2\omega-$ripple reflected by the second inverter due to phase opposition of the ripples at the DC bus. For the same loading of the inverters, the ripples cancel each other at the DC bus. For different loading condition of the inverters, the equivalent ripple is available after cancellation due to the different current loading of inverters. Therefore, the modulation indexes are varied for the further minimization of the equivalent ripple at the DC bus. In next Section, the organization of the Thesis is presented.

1.4 ORGANIZATION OF THESIS

The Thesis is organized in the seven Chapters and the content of the each Chapter is briefly discussed here,

Chapter First: This Chapter presents an introduction of the second-order harmonic ripple problem in the single-phase inverter. The Chapter presents the main objective, motivation and organization of the Thesis.

Chapter Second: The Chapter covers a comprehensive literature review based on the existing methods and techniques to mitigate the second-order ripple problem.

Chapter Third: This Chapter presents the mitigation of the second-order harmonic ripple problem in the two-stage boost-derived DC-DC-AC converter. In this Chapter, a robust adaptive-sliding mode controller is proposed. and the SHC ripple mitigation technique using proposed controller, existence of the sliding mode, stability of the sliding mode and robustness analysis are presented. Furthermore, a comparison of the proposed controller and the some existing controller is presented.

Chapter Fourth: This Chapter presents a modified version of the proposed adaptive-sliding mode controller for the quasi-switched boost inverter. In this Chapter, the ripple-mitigation capability of the proposed controller with improved line-load transients is investigated on the q-SBI with its added feature of the shoot-through operation.

Chapter Fifth: This Chapter presents ISM based controller for the boost-derived two-stage DC-DC-AC converter to mitigate the SHC ripple problem and to improve the dynamic performance of the system. The new adaptive PI controllers in a dual-loop control scheme are introduced as the nominal controller of the ISMC. The performance analysis of the adaptive PI controllers based dual-loop control method over the conventional dual-loop control method is presented. Moreover, the robustness of the proposed ISM based controller against the disturbances and uncertainty in the system is investigated.

Chapter Sixth: This Chapter presents, firstly, a study on a typical DC microgrid in the context of the second-order ripple problem. Secondly, a phase-adjustment control technique using two inverters connected at the DC bus is presented. The control cancels the $2\omega-$ripples reflected by two

inverters at the DC bus. The control is verified through the simulation using MATLAB-Simulink.
Chapter Seventh: This Chapter concludes and discusses the major contributions of the Thesis. The chapter also presents recommendations for the future research.

1.5 PUBLICATIONS

1. A. R. Gautam and D. Fulwani, ”Adaptive SMC for the Second-order Harmonic Ripple Mitigation: A Solution for the Micro-Inverter Applications,” in IEEE Transactions on Power Electronics. doi: 10.1109/TPEL.2018.2882646

2. A. R. Gautam, K. Gourav, J. M. Guerrero and D. M. Fulwani, ”Ripple Mitigation With Improved Line-Load Transients Response in a Two-Stage DC-DC-AC Converter: Adaptive SMC Approach,” in IEEE Transactions on Industrial Electronics, vol. 65, no. 4, pp. 3125-3135, April 2018. doi: 10.1109/TIE.2017.2752125

3. A. R. Gautam, Rammohan R. Makineni and D. M. Fulwani, ”Integral Sliding Mode Control for Boost-Derived DC-DC-AC Converter”, IEEE Transactions on Power Electronics (Under major revision).

4. A. R. Gautam, Rammohan R. Makineni, D. M. Fulwani, and Akshay Kumar Rathore,”Control Strategies and Power Decoupling Topologies to Mitigate $2\omega-$Ripple in Single-phase Inverters: A review and Open Challenges”, IEEE Transactions on Power Electronics (Under Review).

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