Abstract

According to a report by NITI Aayog, the policy think tank of the Government of India, the electronic market is amongst the largest and fastest growing manufacturing industry across the globe; of which computer systems and consumer electronics make about 40% of the total share. Majority of these appliances use a full-bridge rectifier at the front-end in order to convert utility AC into specific DC. The rectification unit, being a non-linear load, distorts the current drawn from the grid. Therefore, power converters are employed in all these appliances not only for harmonic-free rectification but also to provide regulated DC. As all these electronic devices demand power from the utility, their large scale proliferation in households and commercial environments necessitates addressing power quality issues. Moreover, their cumulative consumption of electricity presents a global challenge in terms of improving their energy conversion efficiency. As the demand for the appliances rises, so do the efforts toward making them more energy efficient and also to keep the mains pollution, due to harmonic current, within acceptable limits. This work addresses these grave concerns by providing novel solutions to improve energy efficiency as well as power factor of the power converters.
Majority of the power converters use fixed frequency control for their operation and are designed to deliver peak efficiency when operating around the rated load. However, their efficiency reduces substantially at light loads, owing to the fixed switching and driving losses associated with fixed frequency switching strategy. The problem is further aggravated because of the relative amount of time the system spends operating far below the rated load. This resulted in the development of various government programs, across the globe, which brought tighter regulations for no/low load power consumption. This is particularly challenging in the cost-sensitive 90 W to 500 W appliances. Thereby, to maintain the flat efficiency curve, throughout the load range, a load adaptive varying switching frequency scheme is proposed as a better alternative to the fixed frequency operation.

The electronic equipment generally engage PFC stage followed by a DC-DC converter stage in a two-stage AC-DC-DC converter at the front end. The efficiency of the device depends on how efficiently the energy conversion occurs at each stage. In line with the above aim, a novel need-based, load adaptive control implementation scheme called Event-triggered Sliding mode control (ETSMC) has been used for power converters. This variable frequency modulation scheme ensures limited control execution, thus keeping the chattering phenomenon of conventional sliding mode control (SMC) under check, while guaranteeing the performance required by the user. In the first work, this strategy has been adopted to serve as a solution for efficiency improvement, especially at low loads, in an isolated DC-DC converter. The strategy involves modulating the control signals only at the time instants when a certain pre-defined condition i.e. the event triggering criterion is met. Thereby, unnecessary switching is avoided. The widely popular Hysteresis modulation based SMC (HM-SMC), adopted to suppress chattering, has been proven as a special case of the proposed ETSMC, mathematically. Moreover, the expediency of proposed ETSMC over HM-SMC has been established.

Additionally, as mentioned, a full-bridge rectifier is employed at the front-end in order to convert utility AC into DC. The process, in turn, distorts the current drawn from the grid. These appliances do not affect the power quality much, individually; however, their cumulative effect is significant. Taking cognizance of this fact, many countries have started to impose regulatory measures like IEC 61000-3-2 Harmonics Standards by the European Union for these devices. These standards were proposed for the first time in the year 1995 with their latest fifth edition put to practice in 2018. These regulations categorized appliances into four Classes (Class A, B, C, and D). The literature provides a plethora of power factor correction converters (PFC), employed right after

the rectifier circuit to make the current waveform meet the regulatory standards. The fundamental principle behind PFC is to make the circuit act as a pure resistor. The notion of Loss-free resistor (LFR) therefore, makes for an ideal and natural choice in power factor application. However, the regulatory bodies do not demand a unity power factor, especially for Class D for which the current limits are expressed in terms of mA/Watt. Thereby, a little flexibility in wave-shaping can be allowed. The most popular control scheme is Hysteresis current control; but this control keeps the current to stay within a fixed band. The size of this band stays the same at all loads, even though the regulatory rules provide the flexibility in harmonic content with the load, thus causing unnecessary switching and associated switching losses. The second work of the thesis extended the proposed Event-triggered Sliding mode control strategy for the power factor correction application. The notion of Sliding mode based LFR (SLFR) has been implemented using event-triggered scheme, such that the control adapts the band with load in order to maintain the current within the varying limit at the same time reducing the switching losses.

The aforementioned SLFR was a pre-defined constant and thus could be applied only for input current shaping application. Therefore, there was a need to introduce an adaptive emulated resistance such that it dynamically changes with the operating conditions, in order to serve the dual purpose of current shaping as well as voltage regulation. In the third work, a novel notion of Adaptive Sliding mode based loss-free resistor (ASLFR) has been proposed. The scheme serves itself as an efficient single-stage PFC solution wherein the two stages of voltage regulation and PFC, dealt separately in first and second work, are combined. ASLFR has been used to achieve the dual purpose of harmonics-free rectification along with excellent system response under transients. Furthermore, an event-triggered implementation of the proposed ASLFR scheme has been presented. This ensured that the harmonic content was always within the prescribed limits for Class D regulations for a reduced switching actions. Initially, the work had been implemented for a single-phase boost PFC commonly used for low/medium power electronic equipment under consideration and then on, in the fourth work it was extended for modular three-phase PFC using single-phase Ćuk converters in high power equipment like Electric Vehicle (EV) chargers.

Sliding mode controllers, discussed in above works, have a finite reaching phase and during this reaching phase the system does not have invariance property. An Integral Sliding mode Control (ISMC) has been discussed in the next work which eliminates the reaching phase thus making the system invariant to disturbances from the starting point. Moreover, it combines with a Classical linear control and thus provides merits of the classical control i.e. ease of design and established literature. In ISM control, the dynamic performance is guaranteed by nominal controller and ISM controller rejects only disturbances. Here, the ISM based controller is used for PFC application. It is able to eliminate the external disturbances entering from the input channel and is also able to compensate for the reduced size of the system parameters. This aspect of ISM, of being able to maintain the system performance even under system parameter variation, motivated the next work on Z-source converters (ZSC). A ZSC is usually modelled as a fifth order system, however, based on the symmetry of the Z-source the system model is reduced to third order for the ease of analysis and reduced complexities in controller design. Nonetheless, this symmetry in the Z-source network is an ideal case because duplicating two elements is always a challenge in practical scenario. Therefore, the system dynamics cannot be represented by the reduced order model and a controller designed using the reduced order model can no longer suffice. The proposed non-linear ISM controller mitigates this uncertainty in parameters if they lie in the matched space of the input. Following this, the conclusion of the Thesis has been drawn and the challenges as well as recommendations for the future research are discussed.

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