# Switch-Linear Hybrid Power Conversion (Ⅰ)

## — The Topologies Based on Source Follower


Qianzhi Zhou, SM, IEEE
School of Electrical Engineering & Information
Anhui University of Technology
Maanshan, P.R.China 243002
Email: azhouqz@hotmail.com

Wenhua Hu
School of Electrical & Electronic Engineering
East China Jiaotong University
Nanchang, P.R.China 330013
Email: ecjtumotor@hotmail.com

Bin Wu, SM, IEEE; Mouzhi Dong
School of Electrical & Computer Engineering
Ryerson University
Toronto,Canada M5B 2K3
Email: bwu@ee.ryerson.ca



## Abstract

The paper presents a hybrid power conversion topology series. They are structured with Linear Source Follower fed by Switch-Filter for getting synthetic good performances in high efficiency, THD, load robustness from step response and category changes. Special operating regulation of the power devices are analyzed, neither like in switch conversion nor like in linear amplifiers. Some comparison experiment results with present typical topologies are presented for proving that the novel topology series have a prospect future.


## 1 Introduction

In some special applications and scientific researches, Bulky linear supplies still operated in low efficiency due to its excellent performances in high stability, accuracy and robustness, which are hard to be replaced by switch power supplies. Is there any way to change this situation? The present paper introduces a power conversion idea neither same as that of linear amplifiers nor same as that of switch converters, which combines both of them in topologies, at the same time, acquires the trade-off merits of them. Hence the novel conversion is named after Switch- Linear Hybrid power conversion (SLH) [1], being named after CTA (Comparing-Tracking-Amplifying) conversion [2], [3] at the end of the last century.

The creation purpose is to find a new way which can keep the excellent performances just similar to that of linear amplifiers, but the efficiency and volume can be similar to that of switch mode power converters in the same size. Here performance is the essential problem, so the idea is still based on linear amplifier. If the low efficiency problem of linear amplifiers can be solved by a kind of special measure, then a satisfactory result could be expected.

To analyze the reason why linear amplifiers get excellent performance but low efficiency, take OCL amplifier operating in Class B mode for an example. First, It has the high fidelity and strong robustness because it operates as an Emitter Follower pair with low output resistance [4], [5]. Second, its highest efficiency cannot prevail over 78.5% (theoretical value, omitted device saturated voltage drop). In conventional linear amplifier systems, DC supplies are popularly adopted to feed the power device circuit, leading to a lot of energies wasted. Therefore, to break through the limitation of the original efficiency, also keep the fundamental performances simultaneously，a good idea is using a special ac supply to replace the DC supply feeding the power device circuit. The special ac supply should be controlled only producing small voltage drops on power devices in every transient dynamically. According to this idea, a series of papers [1], [2], [3], [4],[5],[6],[7] have shown above synthetic good performance in trade-off at high efficiency and excellent waveforms, in which the efficiency of the linear unit can be as high as 97% [2],[3]. The efficiency of a MOSFET Source Follower Pair fed by a Smart Wave Amplifier (SW, a special ac supply) was tested as high as 96.3% in 110V network. The fact means that once the SW is replaced by a switch-filter unit with high efficiency, forming a Switch-Linear Hybrid (SLH) circuit, the efficiency of SLH can be expected above 90%, depending on what kinds of switch circuit and power devices are adopted in the former switch-filter. Also the main advantages of linear amplifiers will be still kept.

Fortunately, several topologies have been created from last century end by know. The research is going on for developing wide applications. This paper (□) will describe the fundamental scheme of SLH, introduce several typical topologies with compared experiments, pointing out the prospect future in industry. Another paper (□), the sister paper of paper (□), will discuss the efficiency of SLH in detail, so that the novel topologies can be accepted by industrial field.

## 2 SLH Scheme and the Topologies

### 2.1 Fundamental SLH based on Source Follower

The initial idea of SLH was removed from a high efficiency audio amplifier [8]. The topology is shown in Fig. 1 where a Class B (or AB) amplifier is fed by an ac supply superposed with tooth-like ripples, not normally by a dc supply. Hence the power devices only undergo about a saturated voltage drops on them, leading to the device loss much less than that in conventional Class B amplifiers. Fig.2 shows, in half cycle, the load voltage Vo is adjusted as a little lower than the ripple source voltage by tracking the gate.

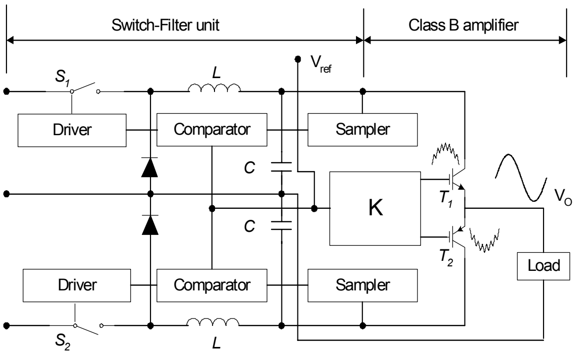



Fig.1 Fundamental SLH (PSLH)

By means of the Emitter Follower scheme, theoretically, this topology can realize arbitrary waveform power conversions with high efficiency and desirable waveforms. As long as set a required reference signal which is coincide with the expected load waveforms in shape, phase, frequency and proportional amplitude, the load waveform will be expected. DC and Sinusoidal conversions are just the special situations among the arbitrary conversions. In other words, the linear Emitter Follower fed by a voltage-tracked switch-filter can acquire the synthetic good performance in waveforms and efficiency simultaneously. In audio amplifier scope, fidelity is emphasized regardless of robustness due to fixed load applications. However in power conversion scope, variable loads are popular, so robustness is also emphasized besides good waveforms and high efficiency. Fortunately the Emitter Follower possesses excellent steady and dynamic tracking feature due to its smallest output resistance among three basic configurations of BJTs. So does the Source Follower of MOSFETs and IGBTs. Meanwhile, Source Followers have higher input resistance and lower output resistance than that of BJTs, acquiring better performance relying upon insulated Gate-voltage control. In Fig.1's topology, in fact, the IGBTs with different channel are difficult to find in market. So two MOSFETs (N-P channel pair) hybridizing a NPN Darlington bridge form the Source Followers, which are inserted between the former unit and the latter one, just like a Power Buffer, either acquiring good robustness to meet the needs of variable loads, including the change from resistive one to inductive one, even to capacitive one, or reducing the mutual influences between the former and latter unit.

One successful example of this topology is in a 3 phases open- loop VVVF-PWM motor system without current-loop, where the motor operates from no load (equivalent to inductive load) to heavy load (equivalent to resistive load). And the load voltage tracks the gate voltage from 5Hz to 60Hz/220V (rms.) with pure sine waveforms, just about several volts lower than that of the filter source. Here the validity is as good as in the situation of pure resistive load. Table 1 shows its good THD operating from 5Hz to 60Hz.

Table1: THD% from V/F-PSLH

| f (Hz) | with load | without load |
|---|---|---|
| 5 | 6.0 | 5.0 |
| 10 | 6.0 | 5.4 |
| 20 | 3.4 | 2.2 |
| 30 | 1.3 | 1.3 |
| 40 | 1.2 | 1.2 |
| 50 | 1.2 | 1.2 |
| 60 | 1.3 | 1.3 |

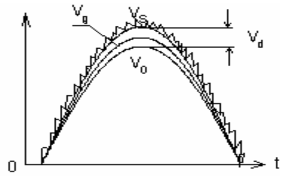



Fig.2 Voltages show Gate-tracked scheme

The topology mentioned above composes of a linear unit fed by a tracking Switch-Filter source. So Switch-Linear Hybrid Power Conversion becomes an acceptable name for one category conversion to distinguish from both pure switch conversions and linear amplifiers. A common topology can be expressed as in Fig. 3. From this unified idea, some reasonable topology branches of SLH can be produced one by one. Typical topologies will be presented in latter pages.

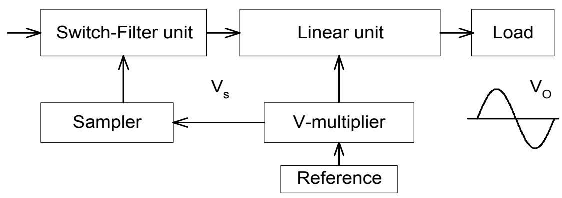
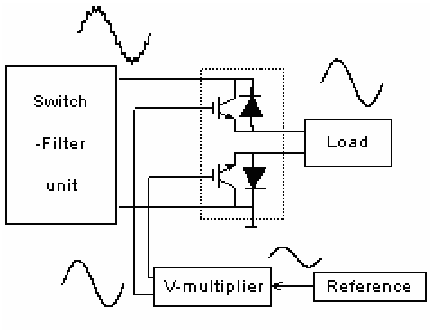



Fig.3 Unified structure of SLH

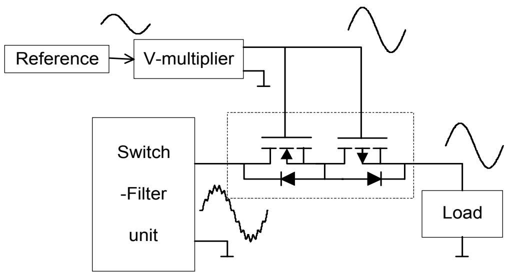
## 2.2 Serial SLH

The drawbacks of the fundamental SLH are those 1) the power device on off-state in the linear unit must undergo the reverse supply voltage; 2) Once a power device of the linear unit operates in breakdown, maybe the former stage of switch unit in parallel with the linear unit would be shorted circuit and burnt; 3) It requires P-channel device to match N- channel device, but the market lacks of IGBTs with different channels ( It had to be hybridized by MOSFET with Darlington artificially at the initial prototype). MOSFETs with different channels cannot be manufactured as high voltage and high current devices like IGBTs. Then, is there another way to realize SLH?

Fig.4 introduces another way to realize SLH, where the Source Followers in linear unit are connected to Switch-Filter-source and the load in series, not like in the fundamental SLH, connected in parallel to the source and load, so this SLH is named after SSLH. Correspondingly the fundamental SLH is named after Paralleled SLH, i.e., PSLH. Here two typical structures of SSLH are shown in Fig.4 [7]. The devices in the linear unit only undergo low voltage drops about the saturation voltage of the device, regardless of the devices at on- state or at off- state. If the linear unit operates in breakdown, the switch unit in former stage will be still safe relying on the serial configuration.




(a) SSLH with the same channel devices

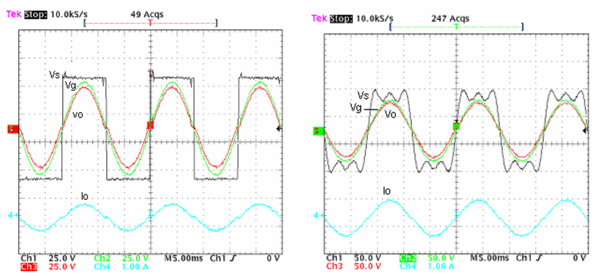



(b) SSLH with the different channel devices

Fig. 4 Single- phase topology of SSLH

Using "Smart Wave Amplifier" to feed a MOSFET Emitter Followers as Switch- Filter unit, structuring the SSLH in Fig. 4., a series of idealized Tracking results can be obtained (See Fig. 5) from the topology in Fig, 4 (a). They prove obviously that as long as the gate voltage regulation is set up, the load voltage will track it steadily and dynamically, regardless of what kinds of sources to feed the Source Followers.

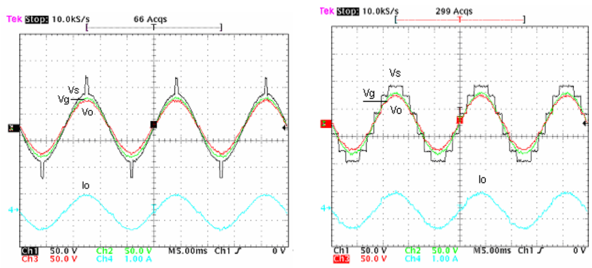
However, the operation scheme in SSLH is not entirely the same as in PSLH. The load voltage of SSLH can track the gate according to Source Follower scheme directly at the positive half cycle, while it cannot do at the negative half cycle, because during the current flows in opposite direction via the MOSFET, the original Source and Drain are just exchanged, i.e., the Source becomes the Drain while the Drain becomes the Source.




(a) (b)

(a) Source waveform is rectangular

(b) Source waveform is the fundamental sine waveform superposed by 5 order's harmonics




(c) (d)

(c) Source waveform is the sine wave superposed by a spike

(d) Source waveform is a step waveform approaching to the fundamental sine waveform

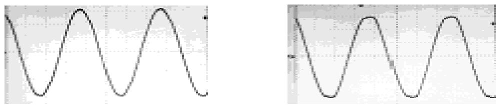
Fig.5 Waveforms to show Gate-Tracked scheme of SSLH

Then the load voltage tracks the gate indirectly. Also the voltage drop on the device (between the exchanged Source and Drain) exhibits a BJT characteristics, which is larger than about 0.7Volt, the imagined value on the inside "anti-paralleled diode". In fact, a BJT structure inside the device on the MOSFET's substrate is an equivalent structure more accurate than that of the "anti-paralleled diode" (equivalent BJT at the substrate omitted base-resistance). In normal operation procedures of the SSLH, the clamp action from the "anti-paralleled diode" is just weakened. Meanwhile the gate voltage is between the Filter output (the original Drain, present Source) voltage and the load (the original Source, present Drain) voltage. Sometimes it is even lower than the load voltage if related parameters are set not reasonable, where the anti-paralleled diode inside the MOSFET becomes the main path of the current and clamps the voltage drop on the device to about 0.7Volt, weakening the action of the reverse tracking of the channel path. So the ripples from the former stage will pollute the negative half cycle of load voltage, which should be avoided. The previous indirect tracking can be defined as a reverse tracking phenomenon, which also presents good waveforms as well as high efficiency like in PSLH. Its steady performance can be similar to the situation of the positive cycle, so like in PSLH. Could the dynamic performance be as good as in PSLH due to the exchange of the Source and Drain? Latter experiments and analyses will reply.

A successful example of SSLH is in UPS application. Table2 and Fig.6 show the comparison information and waveforms between PWM-Filter-UPS and SSLH-UPS respectively. It is obviously that SSLH based on Source Follower has stronger robustness suitable to R, R-L, R-C, and non-linear load even load shock than present UPS based on pure switch-filter scheme.

Table2: THD%-comparison between SSLH-UPS& PWM-UPS in 1kVA size

| Load category | SSLH-UPS | PWM-UPS | Test load |
|---|---|---|---|
| R/460W | 1.34 | 1.75 | Normal light |
| Rectifier-C | 1.3 | 4.18 | 2 computers |
| Thyrister-L/500W | 1,74 | Don't allow | Varable speed-drill runs fast to lock |
| Rectifier-C plus thyrister-L/500W Total 630W | 1.37 | Don't allow | 2 computers & a Varable speed-drill |

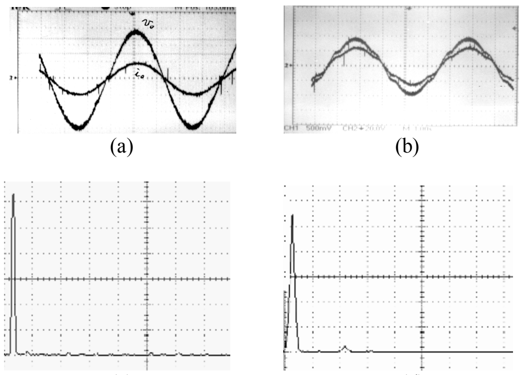


(a) (b)

(a) Output voltage from a 1 kVA of SSLH-UPS with 2 computers
(b) Output voltage from a 1 kVA of SPWM-UPS with 1 computer

Fig.6 Waveform comparison between SSLH-UPS &SPWM-UPS

Another try in a 3 phases of VVVF open-loop speed control system without current-loop also shows the synthetic performance of SSLH is better than that of open-loop PWM system in the same control strategy, operating in ultra low frequency ranges. Fig. 7 shows the comparisons between them.



(a) (b)

(c) (d)

(a) Load voltage and current of SSLH-Inverter with 0.6kW motor
(b) Load voltage and current of SPWM-Inverter with 0.6kW motor
(c) Load current spectrum of SSLH-Inverter with 0.6kW motor
(d) Load current spectrum of SPWM-Inverter with 0.6kW motor

Fig.7 comparison waveforms in 0.2 Hz open-loop V/F-system

### 2.3 Three phases' topologies of SLH

A simple method to implement the SLH topologies in 3 phases is structuring above single-phase topology into 3 phases. The previous examples of motor control in PSLH and SSLH are just obeying this method to form 3 phases' system. The former was in Y-connection while the latter in Δ-connection, without changing the original configurations in single phase.

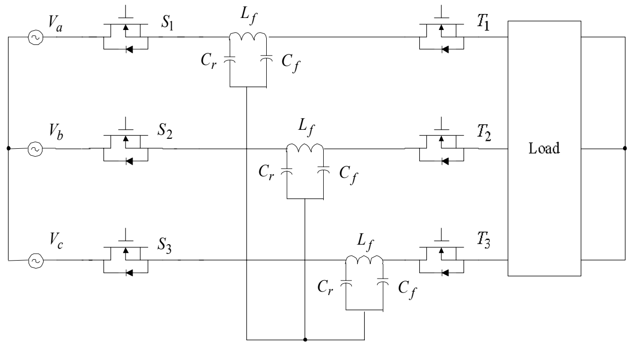
However multiplied power devices must be adopted for hybrid circuits, leading to the cost increase and reliability decrease. Hence, typical topologies of 3 phases-SSLH saving devices are created as in Fig.8 (3phases-3lines system) and Fig.9 (3phases-4lines system), where the combinations between the Switch-Filter unit and Linear unite does not hybridize the present traditional circuits simply.

**(a) SSLH with 3 devices inside the linear unit**

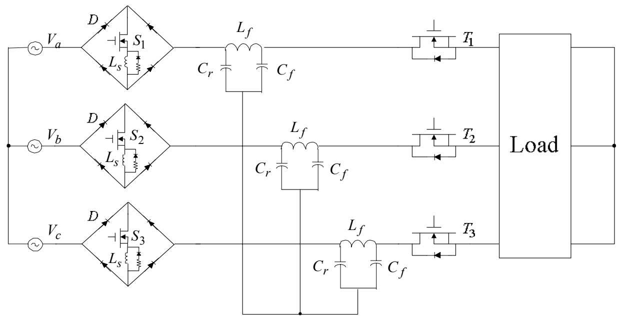
Taking the topology in Fig.8 (a) as an example, it composes of an ac chopper with 3 switch devices controlled by Duty Cycle and a Source Follower with 3 linear devices fed by 3 Line's voltages from above chopper. Apparently, freewheeling devices in traditional 3 phases of choppers [9] are omitted in SSLH for saving devices. However the freewheeling paths still exist. Here the freewheeling capacitance Cr designed much smaller than that of the filter capacitance Cf, so that the LC filter parameters cannot be affected. Also the LC parameters can be designed smaller than that of the traditional switch-filters relying upon the ripples dropping on the devices in Source Followers of the linear unit. While 3 switch devices are all off, the energy stored in 3 filter inductors (Lf) flows via Cf and Cr back to Lf, or flows in the opposite direction, during the device is in off-state after the on-current changes the flowing direction. Cr also acts as a switching-off snubber limiting the dv/dt of the rise voltage at the off transient.

Since Line voltage feeds the linear unit across 2 phases, leading to the voltage on the loads in Y-connection tracking the gate voltages of 2 devices across 2 phases corresponding to the related line voltage. Fig.10 shows the waveforms' comparisons between the topology in Fig.8 and the same topology omitted the linear unit becoming a pure switch-filter converter.

The thing interesting is that not only the load waveforms of 3 Line-SSLH can be much better than that of the pure switch-filter chopper (See Fig. 10(a) and (b)) while connecting the rectifier bridge-filter load, but also it can be better than that of connecting the resistive load by means of its load re-filtering. It is the same situation in connecting the rectifier-inductive load. So the phenomena in SLH are just opposite to traditional switch-filter converters. Then compare their robustness of step load response in Fig.10(c) and (d). It can be found that the load voltage firmly tracks the gate, regardless of the load's stepping-up from 100Ω to 50Ω, or stepping-down from 50Ω to 100Ω, even the source voltage feeding the linear unit has been distorted due to the load's step-shock. Then the question is why the robustness of SSLH in negative half cycle is still good, not affected by the exchanged device drain and source in reverse gate-tracked condition. It can be explained that since the voltage on the real load feeds the device as if an "supply" in this situation, while the output terminal of the LC filter as if an special equivalent "load" fed by a low output resistance "supply". So the voltage waveform of this "supply" gets the robustness to block an action from the "load" (LC-Filter ripples and distortions). This is just the reason that the load robustness of SSLH in an indirect reverse- tracking state at the negative cycle can be good similar to that at the positive cycle.




(a) Topology of 3 switches with 3 linear devices




(b) Topology of 3 switches plus fast diodes with 3 linear devices

Fig.8 3 phases-3 lines SSLH

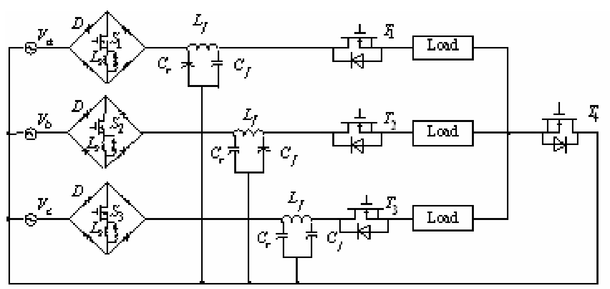
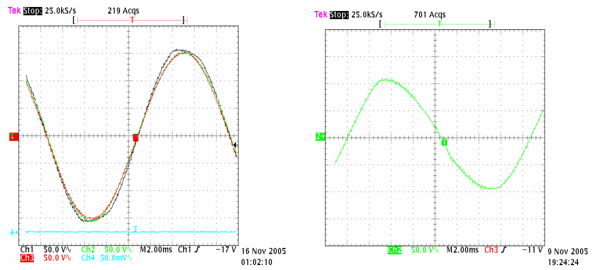


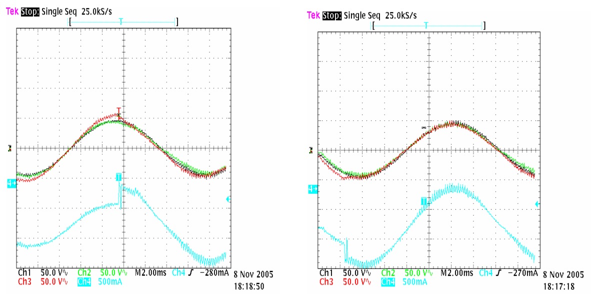

Fig. 9 3 phases-4 lines SSLH

Also this topology has a small range of shift-tracking function, i.e., while the gate voltage shifts a small angle from the source voltage, the load voltage can still track the gate (See Fig.11). So, if a shift-correction unit with fixed trade-off parameters is available, it could be expected that good load waveforms covering the voltage range from 40% Duty Cycle to 96% Duty Cycle. Light distortion waveforms appear over the range of 40% Duty Cycle to 30% Duty Cycle. Only below 30% Duty Cycle, in quite low voltage's condition, the waveforms gets to bad. This result should be acceptable by industrial transformers application for replacing the bulky auto- for regulating voltages. Once advanced microprocessor is available for shift-tracking softly, excellent waveforms would cover the whole voltage-adjustable range from 10% Duty Cycle to 96% Duty Cycle. Of course, if the device gate is polluted by ripple signals or distorted for any reason, the load voltage will also track the ill gate voltage (Fig.12), which should be just avoided.



(a) (b)

(a) SSLH gets fide voltage on the rectifier bridge-C-R load (C: 200μF, R: 100Ω) without following the distortion Source
(b) Switch-filter converter gets distortion voltage on the rectifier bridge C-R load ( C: 200μF, R: 100Ω)

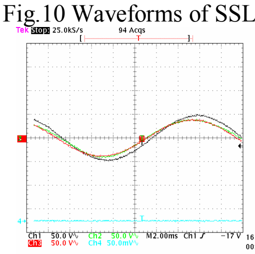


(c) (d)

Upper traces: source & load voltage
Bottom trace: load current

(c) Load voltage response to current step-up (100Ω to50Ω)
(d) Load voltage response to current step-down (50Ω to100Ω)

Fig.10 Waveforms of SSLH in Fig.8 showing load robustness



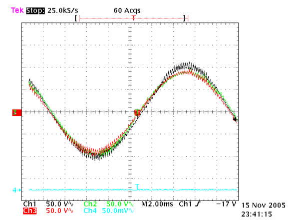
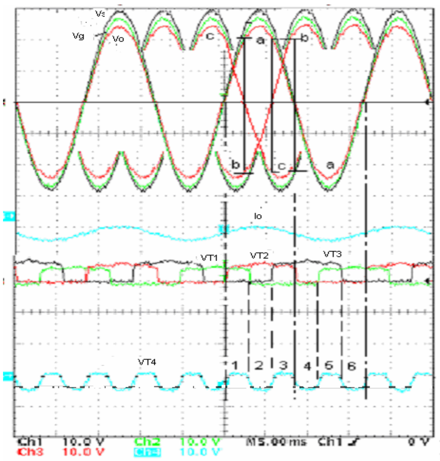


Fig.11Shift-tracking action Fig.12 Load voltage tracks ill gate

### (b) SSLH with 4 devices inside the linear unit

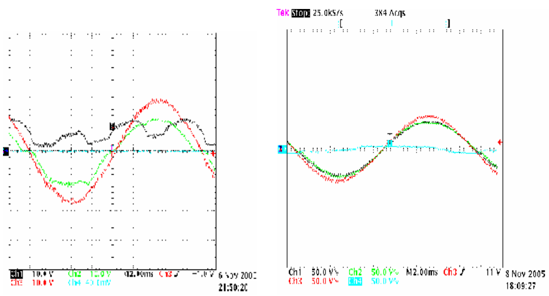
Sometimes 3 phases-4 lines system has to be required. The topology in Fig.9 can realizes it. Introduce the 4th device to form a common path of 3 phases, where T4 operates just like a wire. The thing most interesting is that T4 allows the 3 phases of currents to flow simultaneously in bi-direction, and still plays an important role as a common Source Follower at the same time. However, in fact, T4 is not a real wire but an active device. The bi-directional currents through it must flow simultaneously via the channel in one direction while via the substrate in an opposite direction. To express the meaning clearly, two pieces of waveform-diagrams are moved into the same coordinate forming a new one in Fig.13, which shows 3phases-4lines SSLH-system operating in low voltage condition.




Upper sine traces: Phase voltages on device source & gate and load
Mid sine trace: Load current in one phase
Mid 3 traces: Voltage drops on T1, T2, T3 ( one after another 120˚)
Bottom trace: Voltage-drop on T4

Fig.13 Typical waveforms of 3phases-4lines SSLH

It is obviously that the voltage drop waveform on T4 is quite different from that on T1, T2, T3, because it exhibits the common path's synthetic result. Meanwhile, T4's voltage drop waveform is not symmetrical in the positive and negative half- cycle of the related phase voltage, which must affect the amplitude of the load voltage with about ±3V, leading to the load voltage waveform slightly asymmetrical in positive and negative half-cycle, since the load voltage is equal to the source voltage minus the sum of T4-voltage and another device voltage in the same phase. This negative effect is apparently in low voltage operation due to the drop voltage occupies a big ratio to the total voltage value on the load. However in high voltage operation, the wave-asymmetry can be omitted (See Fig.14). Fortunately, the voltage drop signal on T4 can be sampled and added into an operation amplifier integrated chip for getting a synthetic gate signal to eliminate T4's effect.



Mid trace: T4- wave, 10V/div. 50V / div.
(a) Low voltage operation (b) High voltage operation

Fig.14 Voltage of source, gate load and the effect from T4

In fact, Fig.8 (b)'s topology is not reasonable as Fig.8 (a)'s, because either more fast diodes must be used, or switch devices' "anti-paralleled diode" can not be available, leading to the switch must suffer bi-direction's current in on- states covering the whole cycle, so decreasing the efficiency. However, if hoping one set of SSLH-equipment serves 3phases-3lines system and 3phases-4lines system alternatively, it is just to meet the needs for easy changing the configuration from 3phases-3lines system to 3phases-4lines system, or vice versa.

**(c) Control strategy of 3 phases SSLH**

Simple control methods can satisfy the implement of previous 3 phases SSLH system. A Duty-Cycle adjustable pulse generator unit is presented in Fig.15. Changing the control voltage of the integrated chip, TL494, can modulate the Duty-Cycle of the pulse-series, so increase or reduce the output voltage from the LC filter (the source feeding the Source Follower). At the same time, the sample signal from the switch-filter unit, proportional to the gate voltage is multiplied to the values of several volts lower than the source voltage by a voltage multiplier (See Fig.16). Then the load voltage tracks the sample signal proportionally in shape, frequency, phase and amplitude without distortion.

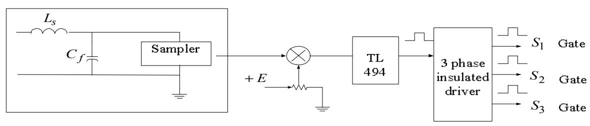



Fig. 15 Switch driver unit

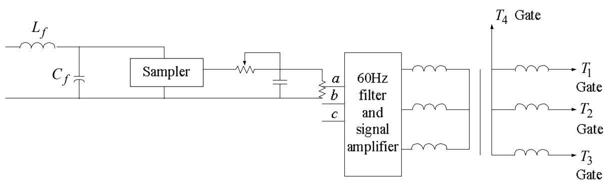



Fig. 16 Source Follower driver unit

If the reference signal is not taken from the output terminal of the LC filter, but taken from an independent microprocessor, in step of the source voltage with expected waveforms in phase, frequency, and proportional amplitude, and adopting electronics circuit to multiply the reference signal, not use boost transformer like in Fig. 16, then V/F control strategy and other advanced motor control strategy can be realized in SSLH system. However ac choppers cannot be used for hybridizing Source Followers for this kind application because the supply frequency cannot be variable. For high performance motor control-SSLH applications, AC-DC-AC topologies should be considered. In this requirement, previous ac chopper need to be replaced by traditional PWM-LC filter unit, but the linear unit composed of 3devices or 4 devices can be still good choices for AC-DC-AC SSLH systems.

## 3 Conclusion

Some SLH topologies (For instance, SSLH with 2lines-input/3lines output in motor control for balancing the central point voltage [10], 3devices-single phase SSLH applied to dynamic Reactive Power Compensator [1], etc.) in past work are omitted in this paper.

The authors notice that another category conversion hybridizing switch circuit with linear one [11] is also a good choice for the same purpose of SLH. Some DC-DC conversion of this category has been applied to microprocessors' supply for good steady and dynamic performances. However the device numbers equal to the sum of the numbers in original switch unit and the related linear unit, also its control strategy is more complex than that of SSLH. While it needs to be extended to 3 phases, or increased the size, the implement difficulties must be more than that of SSLH. Summing up above, Relying upon the extremely high input resistance and low output resistance of Source Follower fed by Switch-Filter, SLH presents a trade-off scheme in structuring power converters, getting synthetic good steady and dynamic performances (low THD, strong robustness in fast response to load step change, suitable to most load categories even non-linear load, etc.), even in open-loop systems. Particularly the 3 topologies of 3 phases-SSLH saving devices can be developed by simple control methods in reasonable cost, instead of traditional linear supplies with high performances and bulky auto-transformers, developing high efficiency- high performance's 3 phases of UPS series and other converter products. Ultra-low speed motor control might be able to utilize the strong robustness to overcome torque and speed ripples that hard to be solved satisfactorily in PWM systems. Once an advanced control strategy is adopted in SLH, it should obtain a better consequence than that of pure switch converter system. SLH-topologies are still a frontier in power electronics field, waiting for further exploration step by step. SLH series would have prospect future in science and industrial applications.

## Acknowledgement

The authors thank to Dr. Congwei Liu for his assistance in recent experiment with great enthusiasm. Also never forget all the SLH group members in Anhui University of Technology to persist the research for long years.

## References

[1] Zhou Qianzhi, "Switch-Linearity Hybrid Power Conversion and Its Application , " *Transactions of China Electrotechnical Society*, vol. 19, no. 8, pp. 28--33, 2004.

[2] Qianzhi Zhou, Zhiguo Chen, Peng Jiang, et al, " A novel high performance frequency changer with sine waves based on voltage comparing-tracking- amplifying (CTA) scheme," *in Proceedings of* 4th *European Conference on Power Electronics and Application,*Florence,Italy,vol.4, pp. 324-329, 1991.

[3] Qianzhi Zhou, et al., "Switch- linearity (CTA) conversion technique based on optimal waveform criterion," *in Proceedings of 1st International Power Electronics and Motion Control Conference,* Beijing, China, vol. 2 pp. 980--985, 1994.

[4] Qianzhi Zhou and Luseng Ge, "Switch-linearity hybrid power conversion (SLH) with low output resistance," *in Proceedings of 4th International Power Electronics and Motion Control Conference*, Xian, China, vol.1, pp. 96--98, 2004.

[5] Zhou Qianzhi,et al.,"Low Output Resistance-Feature of Switch-Linearity Hybrid Converter and Its Effect on the System's Performance Optimization," *Journal of Shanghai Jiaotong University*, vol. 37, no. 9, pp.1375--1379, 2003.

[6] Zhou Qianzhi, et al., "Comparing – Tracking – Amplifying Frequency Changer," *China patent*, No.87106881.8, 1991.

[7] Zhou Qianzhi, Xu Haibin and Wu Dongsheng, "Tracking-type Active Power Filter," *China patent* No.ZL00112420. X 2003.

[8] Kashiwagi s, et al, " A high efficiency audio power amplifier using a self – oscillating switching regulator," *IEEE Trans. on Industry Applications*, vol. 21, no. 4, pp. 906-911, 1985.

[9] Donato Vincenti et al., "Design and Implementation of a 25 - kVA Three - Phase P W M AC Line Conditioner," *IEEE Transactions on Power Electronics*, vol. 9, no. 4, pp.384-389, 1994

[10] Zhou Qianzhi, Zhang Handong and Zhuang Kai, "A single-three phase inverter adopting SLH scheme," *Journal of University of Electronics Science & Technology of China,* vol.32, no.6, pp.655--660, 2003.

[11] Andrés Barrado, Ramón Vázquez, Emilio Olías, Antonio Lázaro and Jorge Pleite, "Theoretical study and implementation of a fast transient response hybrid power supply," *IEEE Trans. on Power Electronics,* vol.19, no.4, pp.1003--1009, 2004.