Optimal Utilization of the Delta Conversion UPS

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Abstract

In this paper, a new configuration for delta conversion UPS is proposed, which could help the system for better utilization of the UPS inverters. In this configuration, parallel and series inverters of the conventional delta conversion UPS, under the grid fault conditions, are connected in parallel which help to share the load power and this results in utilizing the series inverter during fault mode. Therefore, using this configuration not only decreases the total capacity of the UPS inverters, but also decreases the system total cost. In the proposed configuration, two inverters have the same sizes and specifications which results in the system modularity that simplifies its implementation and maintenance and reduces the manufacturing and life cycle cost of the UPS system. In addition, the proposed configuration increases the system reliability. To illustrate proper operation of the proposed configuration, some simulations are carried out under the different conditions. The given simulation results validate appropriate operation of the proposed configuration.

Keywords— Delta conversion UPS, Parallel inverter, Uninterruptible power supply (UPS).

1. INTRODUCTION

Creating and developing usage of critical loads such as: information technology equipment, communication systems and medical devices, in addition to power quality issues, increase UPSs usage [1]-[5]. Existing power systems are unable to supply reliable and high quality power for critical loads and some problems such as voltage sag, swell, harmonics, faults and outage of the grid are always may occurred. UPSs provide reliable and uninterruptible power for sensitive loads [6]-[8]. Most of the UPSs especially delta and double conversion types are able to compensate grid voltage problems such as: harmonic distortions, noise, sag, and swell [9]-[11].

Continuous researches to enhance UPS performance and development of power electronic devices lead to introducing a new generation of line interactive UPS which is called as delta conversion UPS [12]. In a delta conversion UPS, problems of single and double conversion UPS such as: disability to fully compensate the load and grid distortions, inverters rated power, and losses were removed. Hence, it is really close to an ideal choice [13], [14]. Conventional topology of the delta conversion UPS is shown in Fig. 1. In this type of UPS under the normal condition, series inverter compensates load current harmonics and also corrects the load power factor. On the other hand, the parallel inverter regulates the load voltage. Under the grid fault condition, only parallel inverter supplies the load through batteries and series inverter has not done anything. Therefore, power rating of parallel inverter should be at least equal to the load power. Series inverter capacity which is used only during compensation mode is equal to 20% of the load power. Therefore, total capacity of the UPS inverters is at least 20% more than the load power (120% of load power) [15]. This is a greatest weakness of the delta conversion UPS. It should be noticed that under the normal condition only a little portion of the parallel inverter capacity is used. In [16] and [17] another control method for delta conversion UPS has been proposed which series inverter regulates the load voltage and parallel inverter compensates loads harmonics and also corrects power factor. To improve delta conversion UPS performance, some modifications on its configuration in [18], [19] and various control methods in [20], [21] have been suggested.

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In this paper, a new delta conversion UPS configuration is proposed which uses the unbound series inverter under the grid fault conditions. In the proposed configuration, the normal operation condition remains unchanged but, under the grid fault conditions, with the aid of paralleling both inverters, UPS operation is changed. This strategy reduces the inverters size, increases the system reliability, and leads to system modularity. Also, it decreases the UPS manufacturing and running cost.
In Section II, conventional control strategy of the delta conversion UPS is described. Section III is given the proposed configuration and its control method and benefits. Also, principle operation of the proposed configuration is discussed, in details. Simulation results are given in Section IV and finally, the paper is concluded in Section V.

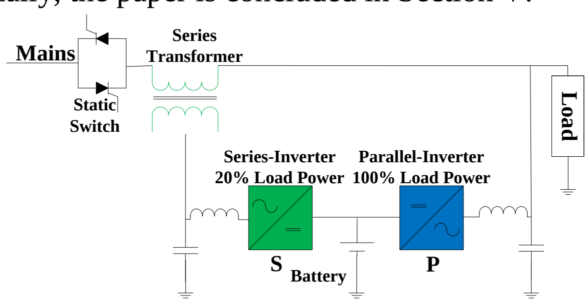


Fig.1. Delta conversion UPS configuration [13]

2. CONVENTIONAL CONTROL STRATEGY OF DELTA CONVERSION UPS

As shown in Fig. 1, delta type UPSs has two inverters which are connected to a common battery bus. Power rating of series or delta inverter (S) is equal to 20% of the UPS output power and it is connected in series with grid through a transformer. Parallel or main inverter (P) rated power is equal to 100% of the output power. The parallel inverter regulates load voltage either in normal condition or grid fault condition. The series inverter is controlled in a way that the grid current is remained sinusoidal and in phase with the grid voltage. In addition, the series inverter controls battery charging. Since the capacity of the series inverter is equal to 20% of the load power, its compensation capability is limited to this value and hence the UPS can compensate the system perturbations' up to 20% of nominal grid condition.
In normal condition with a linear load, the grid provides active power of the load, the parallel inverter supplies load reactive power and the series inverter only corrects power factor. Fig. 2(a) shows the active and reactive power transfer paths in this operation condition.

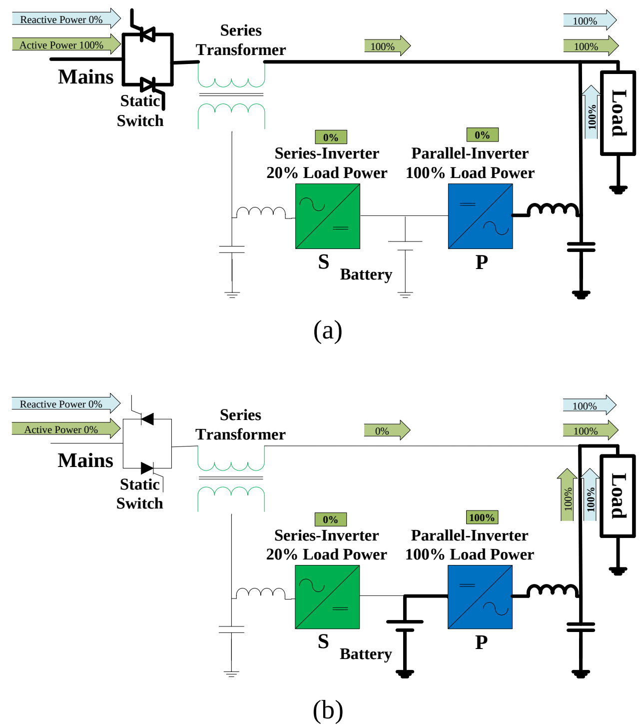


Fig. 2: Power flow paths in the delta type UPS a) normal condition and b) grid fault condition

By occurring a fault in the grid, the series inverter is ceased and the parallel inverter supplies the load, solely. Therefore, the capacity of the parallel inverter must be at least equal to the load power. Fig. 2 (b) illustrates power transfer path for this situation. As seen in this figure, the series inverter has no action in this mode and its capacity is unbound. The proposed configuration, which will be discussed in the next section, uses this free capacity, as well.
As it can be seen in this figure, the series inverter is paralleled with the main inverter through a static switch (L). After a fault occurrence in the grid, this static switch parallels the two inverters at load phase voltage zero crossing.
Parallel operation of the inverters is used in UPS systems for increasing capacity, redundancy, and reliability [22]. Because of the natural limitations of semiconductor devices, the inverters power ratings are limited. Paralleling the inverters can overcome this problem [23]. A system with several

paralleled inverters is modular and therefore has higher reliability [24-25]. Paralleling the converters also simplifies UPS system maintenance. In the two next subsections operation modes of the proposed configuration is given, in details.

2.1.Normal operation mode of the proposed configuration

Under the normal mode condition, load is supplied through the grid. In this situation static switches N and L (Fig.3) are on and off, respectively. During normal operation mode, power flow is as the same as conventional delta conversion UPS which shows in Fig. 2(a). Parallel inverter regulates the load voltage which must be kept at the desired value regardless of the load type (linearity or non-linearity) or grid distortions and fluctuations (sag, swell…). This has been done by using a closed control loop in Fig. 4. Here, the voltage error is applied to a proportional-resonant (PR) controller to produce a current reference. Finally, inverter switching commands are generated by applying the generated current error to a tuned controller. To improve the inverter transient response, a feed-forward path between the voltage and switching commands is considered, too.

The series inverter is controlled in a way that the grid current remains sinusoidal with unity power factor regardless of the load type and conditions. It should be noticed that the grid current is controlled by the aim of series inverter such that harmonics and reactive power are supplied by the parallel inverter. The series inverter also controls the DC bus voltage. Fig. 5 shows the series inverter control block diagram for this operation mode. According to Fig. 5, only "d" component of the grid current is delivered to the current controller in a way that the grid provides only the load active power. By Eliminating "q" and "0" components of the load current, the load power factor is corrected and its harmonic content is reduced. To control the dc bus voltage, output of the dc bus voltage controller is added to "d" component of the load current, too. In other word, the system try to correct the power factor, hence only "d" component of the load current should supply by grid. On the other hand charge current of the battery should supply by the grid too. Hence the output of PI controller (output of DC bus voltage controller) added to i_d. In this way only active power drain from the grid and "q" and "0" component of load current which are the result of reactive power and load current harmonic content should compensated by UPS.

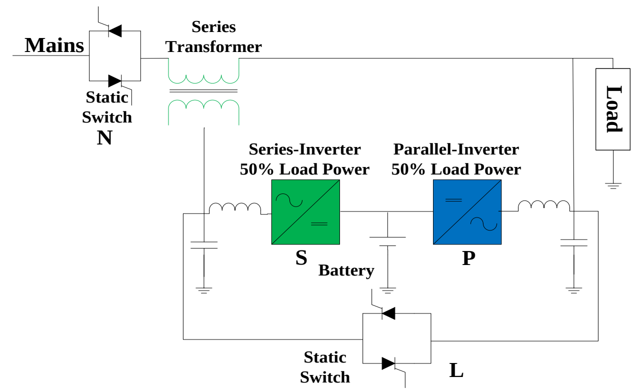


Fig. 3: The proposed configuration for the delta conversion UPS

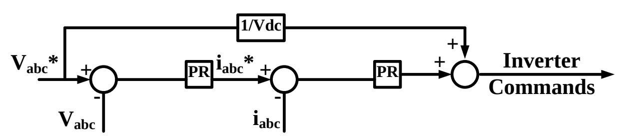


Fig. 4: control loop of the parallel inverter in the proposed configuration

In the figure V_{dc} is the measured DC bus voltage and V_{dc}^* is the desired and reference voltage for the DC bus. The battery voltage is constant when there is no delivering current but, when a current is drained from battery the voltage will decrease (due to the internal resistant of the battery). It should be considered that when there is no need for power form the battery and hence no current drained from it, the bus voltage is equal to the battery voltage but, if the battery gives current to the system its' voltage drop and the controller should come in act and try to maintain the DC bus voltage in the preset value (V_{dc}*), also the difference between the DC bus voltage and the desired DC voltage determine the charging current of the battery.

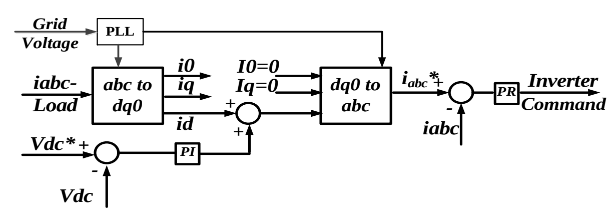


Fig. 5: Series inverter control block diagram under the normal condition

2.2. Grid voltage fault operation mode of the proposed configuration

Under the grid fault condition, the output load is only supplied by the UPS batteries and hence in the proposed configuration static switches of N and L are off and on, respectively (see Fig. 3). This leads to inverters paralleling and load sharing. Fig. 6 depicts power flow of the proposed configuration in this condition. Unlike the conventional configuration approach of the delta conversion UPS, by implementing this new approach, capacity of the series inverter is used to provide the load power. On the other hand, increasing the capacity of the series inverter to 2.5 times of conventional delta conversion UPS, results in increasing compensation capability of the UPS by 250%.

Surge current event can be occurred at the moment of paralleling the two inverters with different output voltages. To avoid these large transient currents, static switch L can parallel both inverters in load phase voltage zero crossing moment. To find the load voltage zero crossing, Load voltage measurement has been used. This happens in this way that, when the absolute value of a load phase voltage is lower than preset value, paralleling static switches (L) parallel that phase of two inverters. Whatever this preset value is bigger the time which parallel inverter handle the load lonely is became less but, the inrush current caused by paralleling is increased. On the contrary by lowering this value the time of paralleling is increase but the inrush current decreased.

It should be considered that the voltage which the grid is disconnected is determined by the voltage and power compensation capacity of series inverter. The mechanism of the disconnecting point is the same in all delta conversion UPSs. If the grid voltage drop below the preset value a command sends to the static switch N to disconnect from the grid and in the proposed configuration another command send to static switch L to parallel the inverters at phase voltage zero crossing. The overall block diagram is demonstrated in Fig. 8.

According to the power rating and transformer ratio of series inverter in the proposed configuration the system could compensate up to 50% of under voltage and after that, system should be disconnected from the grid (in conventional configuration the system could compensate up to 20% of voltage sag due to 20% power rating of series inverter). On the other hand, when the grid voltage drops, to fully supply the load, grid current increases, hence the grid current flow rate should be considered.

Paralleling two inverters requires a load sharing algorithm. Although, all load sharing algorithms can be implemented, but, master slave method is used here by changing the series inverter control approach, as shown in Fig. 7. According to this figure, the parallel inverter current ($i_{abc\text{-}P}$) is used as the current reference of the series inverter ($i_{abc\text{-}S}$ is series inverter current). The current controller decreases the error to equalize both inverters currents and to complete load sharing between them. In other word, after two inverters has been paralleled, parallel (main) inverter act as master and in charge of controlling and regulating the load bus. In this situation, the series inverter acts as slave. The parallel inverter current is a reference for the series inverter current in the controller, as shown in Fig. 7. If the current controller works fine, currents of the inverters became the same (equal to: load current/2) and considering the constant voltage of the load, the load power divided equally between the inverters. Hence the series inverter controlled depending on parallel inverter and acts as slave inverter.

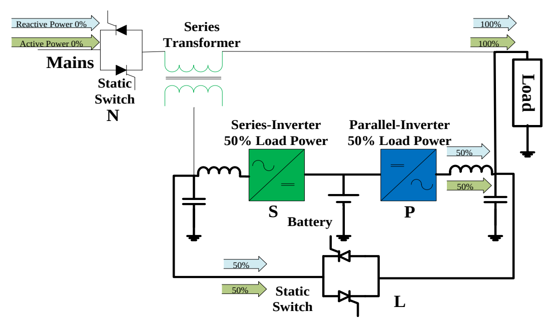


Fig. 6: Power flow paths of the proposed configuration under the grid fault condition

According to the proposed configuration and related control, with the help of proposed configuration, total UPS inverters rating is reduced from 120% to 100% of the load power value.

The proportional-resonant controller is used to avoid transferring feedback current to “dq0” reference frame and to return it back to “abc” frame. Resonant controller removes steady state error at the desired frequency. In case of non-linear load condition, a resonant controller can be used for each harmonic, which leads to equally sharing of the current harmonics between the inverters.

Fig. 8 shows the overall system block diagram consisting of system proposed configuration and its' control method. As it could be seen the series inverter has two control strategy, one for normal condition and the other is for grid fault condition but, parallel inverter only have a single control strategy and its control method did not change. The command to the static switches was determined by grid and load voltage as stated before.

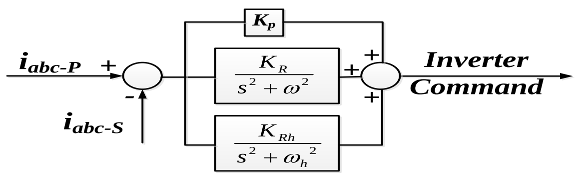


Fig. 7: Control block diagram of the series inverter under the grid fault condition

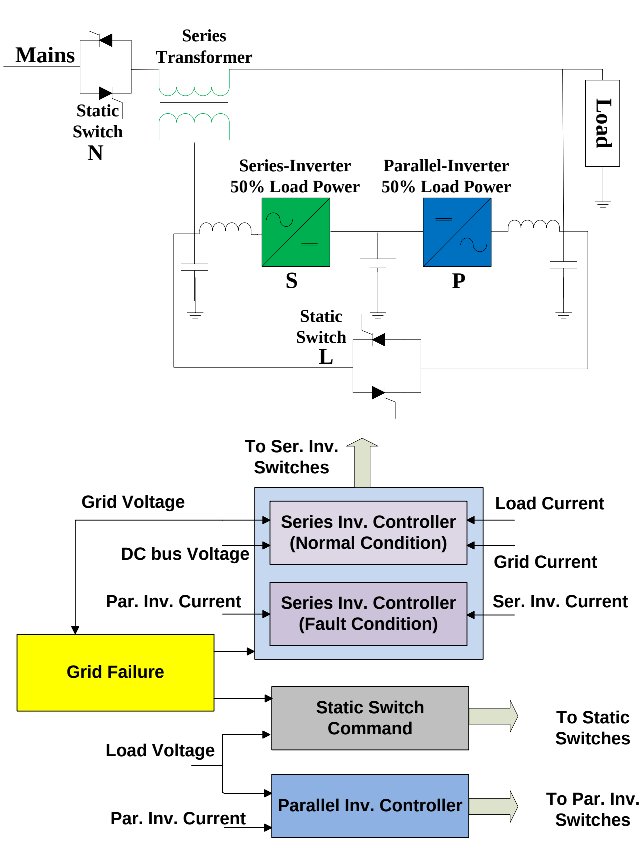


Fig. 8: Overall system block diagram

2.3.Cost analysis of the proposed configuration

In this section, the proposed configuration is analyzed from cost point of view. For this reason, load is considered to be 5 kW with power factor of 0.8 lag. Considering this power factor and the output voltage (380 V) values, inverter rated current or, better to say, its switches rated current values for different capacities equal to 100%, 50% and 20% of the load power are equal to 9.5A, 4.7A and 1.9A, respectively.

Table I shows main specifications of some selected switches and their cost using Digikey [26] database. All of these switches which are manufactured by ST are selected to provide the desired load current at 100 ℃ junction temperature. MAC9DG is a Triac switch used for the static switch L. it should be noticed that static switch N are the same in both proposed and conventional topology and it is necessary for all UPS to have a static switch for isolating from the grid. Hence the price of these switches was not inserted in the analysis.

Considering Table I, costs of the inverter main power components (switches) for 20%, 50% and 100% of the given load power value are 9.5922$, 11.7576$ and 24.6288$, respectively and the price of static switch L in the proposed configuration is 2.01$. Based on these calculated values, prices of the conventional and the proposed configurations delta conversion UPS inverters are 34.221$ and 25.5252$, respectively. Therefore, using the proposed configuration reduces the system total cost (approximately 25%). Since the proposed configuration reduces total capacity of the UPS employed inverters, its total price is reduced as well, as expected. It must be mentioned that this value could be reduced more by increasing the load power value.

TABLE. I. SELECTED SWITCHES FEATURES

Part number	*Rated voltage (V)*	*Rated current (A)*		*Price($)*
		at 25℃	*at 100℃*	
IPW65R280	*800*	*16*	*100*	*4.1048*
IPW65R190	*800*	*8*	*5*	*1.9596*
IPW65R150	*800*	*3.6*	*2.8*	*1.5987*
MAC9DG	*800*	*8*	*5*	*0.67*

2.4.Reliability analysis of the proposed configuration

In this section, reliabilities of the conventional and proposed configurations are compared, in details. Since the principle operations of these both configurations are the same under the normal condition, this comparison is done only for grid fault condition. In conventional configuration a 5 kW load is supplied by a 5 kW inverter. But, in the proposed configuration it is supplied via two 2.5 kW paralleled inverters. For 380 V line voltage and 740 V DC bus, the rated current values of 5 kW and 2.5 kW inverters are equal to 7.6 A and 3.8 A, respectively. Rated voltage value of the selected switches is equal to 800 V. IXFA10N80P switches with rated current of 10 A and R_{sd}=1.Ω is selected for 5 kW inverter. Also, IXFA7N80P switch with rated current value of 5.4 A and R_{sd}=1.44 Ω is selected for 2.5 kW inverter. Here, a pure resistance is considered as the load. The switches losses for 5 kW and 2.5 kW inverters are 31.8W and 10.4W, respectively. MOSFET failure rate is defined as follows [27]:

$$\lambda_P = \lambda_b \pi_T \pi_A \pi_Q \pi_E \quad \text{(Failures/106Hours)} \tag{1}$$

These parameters are depend on the MOSFET operation conditions and they were obtained from the above mentioned standard, except π_T , which is related to the MOSFET junction temperature and it must be calculated, separately. The other parameters are given in Table II.

TABLE. II. RELIABILITY PARAMETERS OF THE CHOSEN MOSFET

λ_b	π_A	π_Q	π_E
0.012	*10*	*8.0*	*1*

Using table II parameters, the MOSFET failure rate equation is obtained as follows:

$$\lambda_P = 0.96\pi_T \tag{2}$$

Eq. (2) shows that the main factor in the MOSFET failure is its junction temperature. Here, π_T is calculated as follows:

$$\pi_T = e^{-1925\left(\frac{1}{T_J+273}-\frac{1}{298}\right)} \tag{3}$$

Considering the ambient temperature is equal to 30 ℃ and heat sink thermal resistance is equal to 2oC/W, π_T values for 5 kW and 2.5 kW inverters are 4.95 and 2.08, respectively. Therefore, failure rate of the inverters are 28.5 and 24, respectively. In other words, using the proposed configuration failure rate reduces by 18.75 % and therefore the reliability of the system increases. It should be noticed that this improvement is proportional to the UPS output power value. Consequently, if the load power rating is increased, then improving the performance of the proposed configuration is more obvious.

3. SIMULATION RESULTS

To demonstrate proper operation of the proposed configuration and its control strategies, simulations are carried out using MATLAB/Simulink. Simulations are done in two sections. At first, to analysis the compensation performance of the proposed configuration under the grid connected condition, the grid voltage is distorted (20% of 3th and 10% of 5th harmonic) at t=0.5 sec and also simultaneously a sag (20%) is occurred. Also, a load is a non-linear one, here. In the second part, at t=1 sec a fault is occurred in the grid which interrupts the grid service. Under this situation, the load is supplied just by batteries and through UPS. The simulation parameters are tabulated in Table. III. In both part the UPS loaded with a full load.

TABLE. III. SIMULATION PARAMETERS

Specifications		Value
Series Inverter Filter		6 mH-22uF
Parallel Inverter Filter		6 mH-22uF
DC bus Voltage		740 V
Switching frequency		5KHz
Load Type		3Phase diode rectifier
Load Active Power		5.7 KW
Load Power Factor		0.9
Inverters Nominal Power		2.9 KW
Load THD		36%
Grid Under Voltage		20%
Grid Harmonic		20% 3rd and 10% 5th
Grid Nominal Voltage		380 V
Battery		Lead-Acid 10Ah
Series Transformer	Ratio	1:2
	Nominal Power	3 VA
	Nominal Voltage	380 V
	R	0.01 pu
	L	0.01 pu

3.1. Grid voltage and load current compensation

Under the normal situation, the load is supplied through the grid and the series inverter corrects the power factor and eliminates the load current harmonics. Therefore, for testing the performance of series inverter, a nonlinear load with reactive power is used in the simulation.

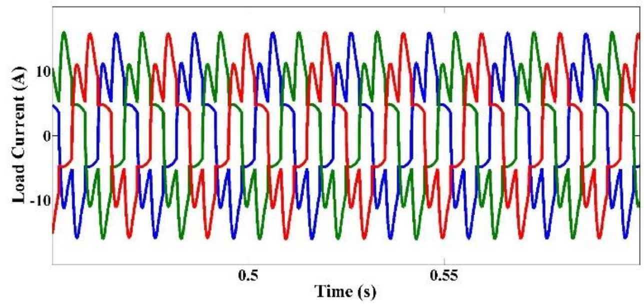
Control goal for the parallel inverter is to supply the load with a balanced three phase sinusoidal voltage with proper amplitude. Effectiveness of this control system could be tested with distorted and fluctuated grid voltage. Fig. 9 shows the load current waveform and its related THD. As it can be seen the load is highly non-linear and its current THD is about 36% which could be a good test for series inverter performance.

Fig. 10 shows the load active and reactive power values with power factor of 0.9. As it could be seen the load active power is around 5400 W and the load reactive power is around 1900 Var.

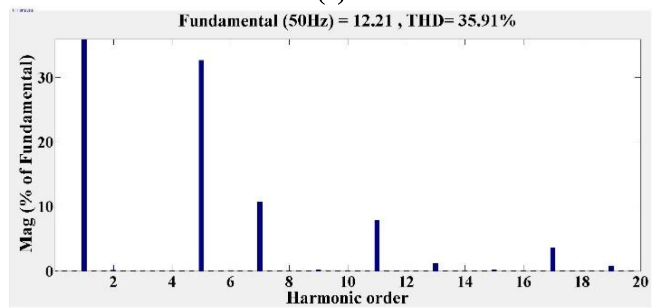
In this operation mode, the series inverter eliminates the load current harmonics and corrects the power factor. Fig. 11 illustrates the grid current and its harmonic contents, respectively. Considering this figure, it can be seen that the amount of harmonic distortion in the grid current is reduced greatly which good operation of the series inverter can be concluded and that is expected.

By focusing in Fig. 11 (a) it could be find out that when the grid voltage drops, parallel inverter try to maintain the load voltage at preset value, for this reason it draw power from the DC bus. By decreasing the Dc bus voltage, series inverter try to fix the problem and hence it tries to draw more current from the grid.

Fig. 12 shows the grid active and reactive power values. Here, the load active power is supplied by the grid, completely. The grid reactive power value is zero and this verifies power factor correction performance of the series inverter. By decreasing the grid voltage, delivered power from grid is decreased, too. But, the grid power reduction is compensated, because the parallel inverter keeps the load voltage unchanged. This could decrease the DC bus voltage. So, the series inverter come in act and increases the grid current to compensate the dc bus voltage drop. Therefore, the grid delivered power is returned to its initial value.



(a)



(b)

Fig. 9: a) load current and b) load current harmonic content

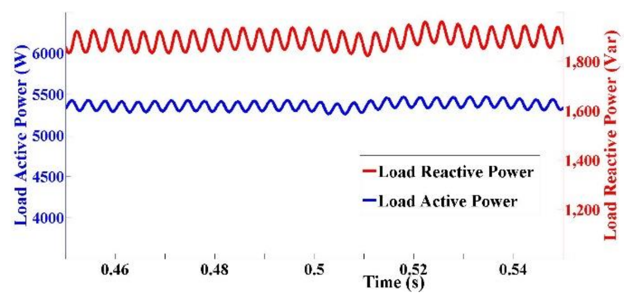
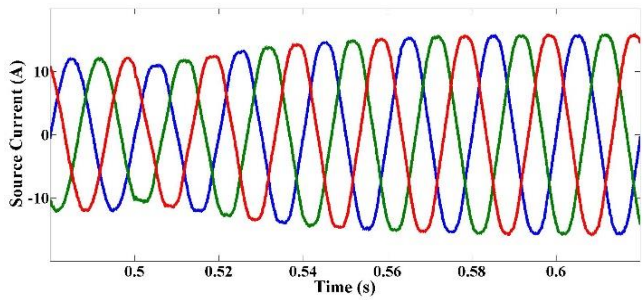
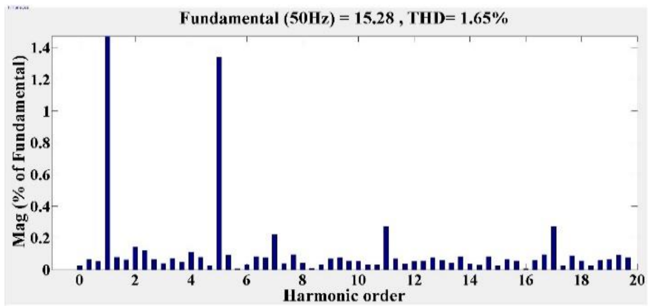


Fig. 10: normal operation mode load active power (left axis) and load reactive power (right axis)

Fig. 12 shows the grid active and reactive power values. Here, the load active power is supplied by the grid, completely. The grid reactive power value is zero and this verifies power factor correction performance of the series inverter. By decreasing the grid voltage, delivered power from grid is decreased, too. But, the grid power reduction is compensated, because the parallel inverter keeps the load voltage unchanged. This could decrease the DC bus voltage. So, the series inverter come in act and increases the grid current to compensate the dc bus voltage drop. Therefore, the grid delivered power is returned to its initial value.



(a)



(b)

Fig. 11: a) grid current and b) grid current harmonic content

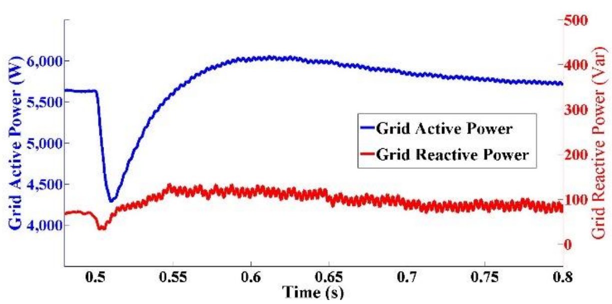


Fig. 12: Grid active power (left axis) and reactive power (right axis)

For investigating the load voltage regulation ability of the parallel inverter, at t=0.5 sec not only some harmonics are added to the grid voltage, but also a sag is applied, too. Fig. 13 shows the grid voltage waveform.

Fig. 14 (a) depicts the load voltage before and coincides with the grid voltage distortion. Fig. 14 (b) shows the load voltage THD. According to Fig. 14, in spite of the distortion and sag in the grid voltage, the load voltage is kept sinusoidal, constant and in the desired value. Additionally, harmonic content of the load current has no effect on the load voltage, which certifies the voltage regulation ability of the parallel inverter, as well.

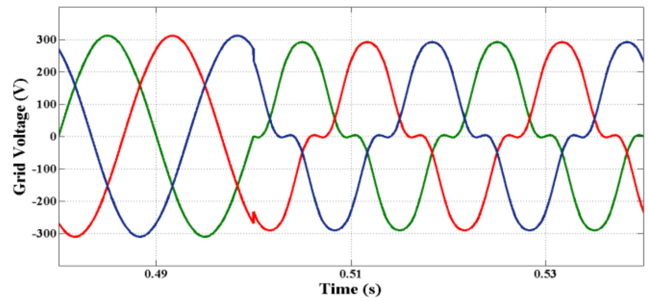
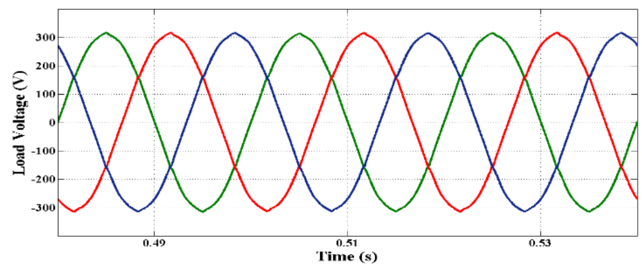
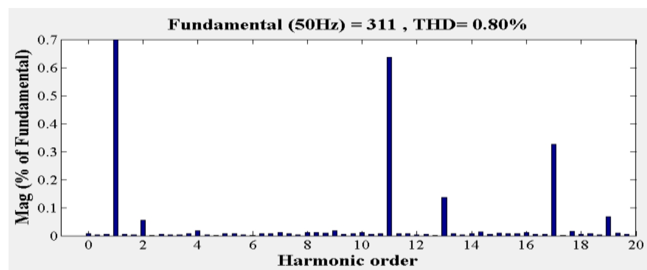


Fig. 13: Grid voltage



(a)



(b)

Fig. 14: a) Load voltage and b) load voltage harmonic content

Fig. 15 shows the DC bus voltage for this situation. It could be seen that at the time of sag and harmonics introduction in grid voltage the DC bus voltage drop about one volt and in less than a second the DC bus voltage come back to its initial condition. It should be noticed that this voltage is the input voltage for series inverter, too.

Fig. 16 and Fig. 17 are shown the input power of series inverter and output power of parallel inverter, respectively. It could be seen that parallel inverter absorb the power and give it to the DC bus. The DC bus give this power to the series inverter which wants to force the grid to increase its' current. By increasing the grid current (Fig. 11 (a)) the load power supplied completely by the grid. In this situation grid deliver a lower voltage and higher current than nominal condition but it is deliver the load power completely due to the series inverter role. The difference between parallel absorb power and input power of series inverter is because of the inverters losses.

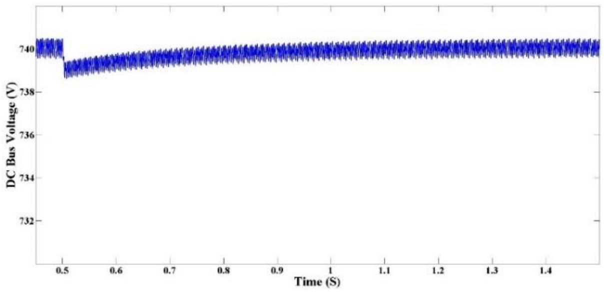


Fig. 15: DC bus voltage (Series inverter input voltage)

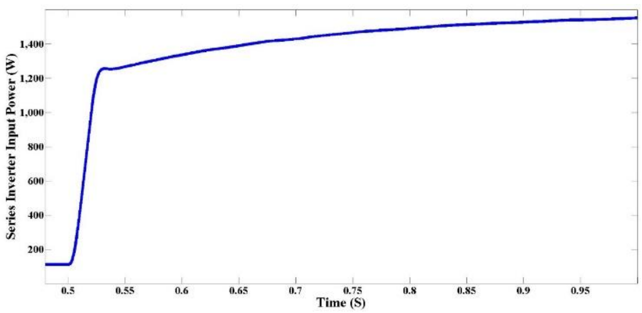


Fig. 16: Series inverter input power

This power did not draw from the grid and it is circulated from parallel inverter to DC bus and from DC bus to series inverter and again go to parallel inverter. Hence this will not affect the load or grid power directly but, because of this power, the output current of series inverter increase and hence the current of transformer series side increase, so the current of other winding of the transformer increases too, therefore the grid current increases.

Fig. 18 shows the parallel inverter output current. As it could be seen due to the non-linearity of the load and also harmonic content of the grid voltage this current is not sinusoidal.

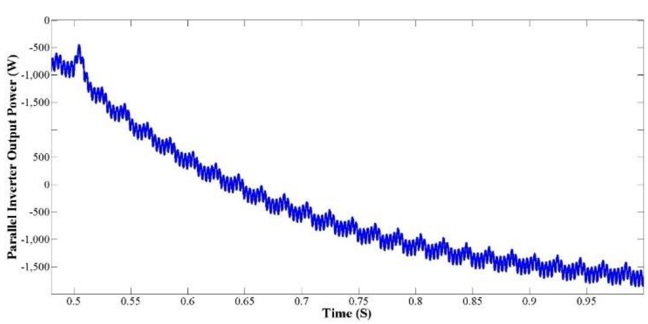


Fig. 17: Parallel inverter output power

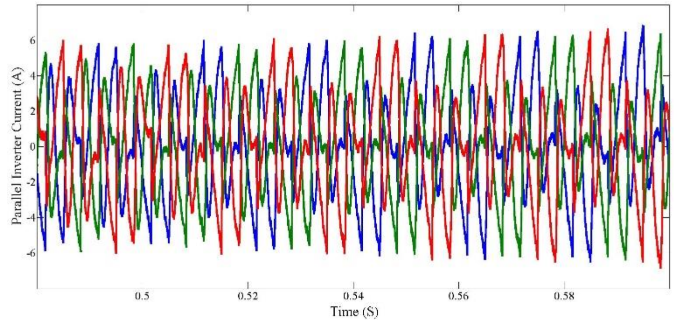


Fig. 18: parallel inverter output current

3.2.Grid voltage fault condition

In this section, the grid voltage is interrupted at t=1 sec and the load is supplied only by the batteries and through inverters. In this situation the static switch (L) parallels both main and series inverters. The parallel inverter operates as master and the series acts as slave. Control algorithm of the parallel inverter is remained unchanged which could eliminate the voltage transients at load side. Fig. 19 shows the load voltage before and after the grid voltage interruption event. As it could be seen the given configuration (two inverter paralleling) and series inverter control algorithm have no effect on the load voltage, as illustrated in Fig. 19 drop value in the load voltage is less than 4.8% which is acceptable based on the power quality standards (CBMA Curve).

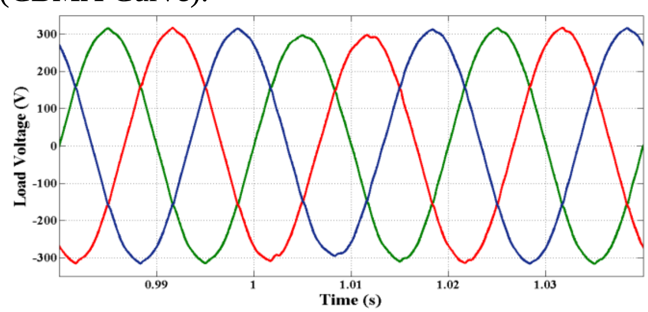


Fig. 19: Load voltage under the grid fault condition

Also, it should be mentioned that changing the UPS operation mode has no negative effect on the load voltage and current waveforms and the load is supplied, seamlessly which certifies the propose method.

Fig. 20 illustrates the load active and reactive power values. It also shows uninterruptible supplying the load, too. Here, the load active and reactive power values are decreased by 10% and 15%, respectively. Then they are returned to their initial values in less than one cycle. This is used to examine the transient response of the parallel inverter under this condition. After turning the paralleling switches on, completely, the load current is shared between both inverters, equally. When the grid interrupted, for a moment of time parallel inverter should handle the load solely and because it could not supply enough current the load active power drops. In less than a cycle parallel inverter could supply the load current by itself and with the aid of series inverter, hence the load power supply completely.

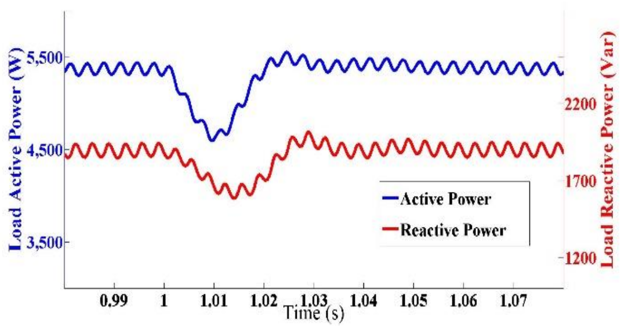


Fig. 20: Grid fault condition load active power (left axis) and load reactive power (right axis)

Fig. 21 shows the parallel and series inverter's currents waveforms, respectively. As it could be seen after a short transient time, inverters currents are become the same (it should be noticed that the scale of charts are different but the value of the currents are equal after steady state). This object demonstrates that the series inverter control algorithm operates successfully after paralleling the inverters. Since, the paralleling switches operate at zero crossing moment of the load voltage, during a short period of time (between the grid interruption event and the zero crossing moments), the parallel inverter carries the current greater than half of the load current value. But, all power semiconductor devices can withstand such transient currents without any damage and there is no problem. Electronic power switches (IGBT, MOSFET …) can tolerate currents more than nominal current for short period of time. The time and amount of this over current is determined by thermal impedance of the switches. Anyway by choosing the proper switch considering the over current and its period (using SAO curve) this issue could be solve. It should be noticed that in all power electronics devices switches with a higher rating than necessary current was used for more reliability and more ability to withstand in inrush currents.

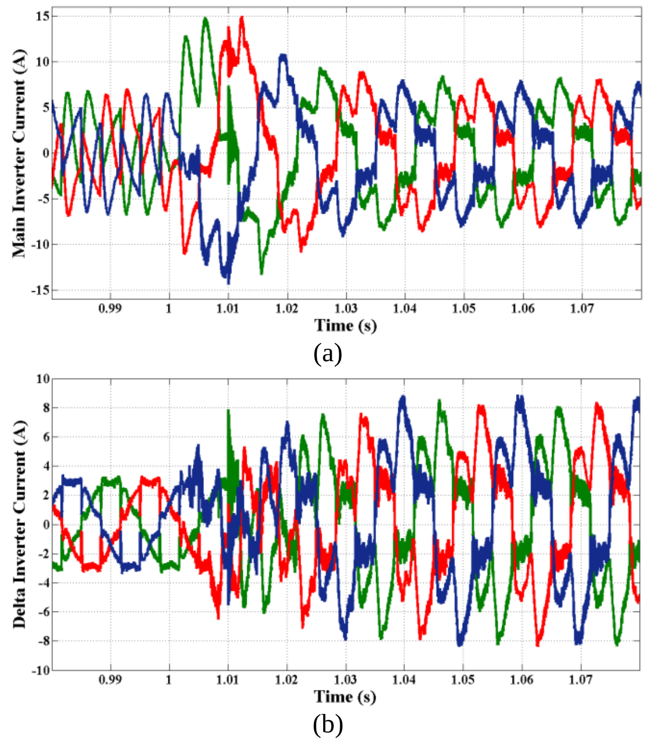


Fig. 21: Grid fault condition a) parallel inverter current and b) series inverter current

Fig. 22 shows active power of the parallel and series inverters. During a short time between the grid interruption and the inverters paralleling moments the parallel inverter supplies the load, solely. After paralleling the inverters and activating the master-slave algorithm, the load current is shared equally between the two inverters. Fig. 22 validates load sharing between the main and series inverters, properly.

DC bus voltage for this situation which is the input voltage of the series inverter is shown in Fig. 23. In this situation input voltage of the series and parallel inverter are the same because both inverters are supplied the load via batteries. It is obvious that when battery started to supply the load the battery output voltage decrease about 6 volts because of internal resistance of the battery. After this, the decrease in battery voltage is very slow. It should be noted that in grid failure condition the DC bus voltage could not be controlled because there is no power flow from the grid and battery power and voltage only could be control via grid power. In this situation the output voltage of series and parallel inverter are the same as load voltage which is depicted in Fig.19.

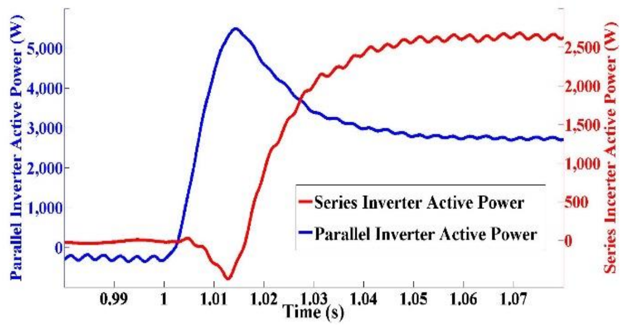


Fig. 22: Grid fault condition parallel inverter active power (left axis) series inverter active power (right axis)

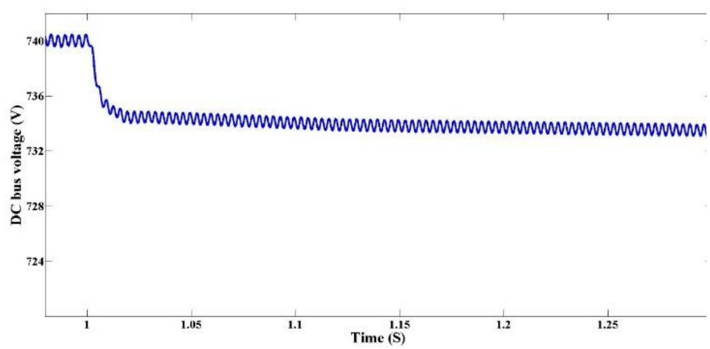


Fig. 23: DC bus voltage (Series inverter input voltage)

4. CONCLUSION

In this paper a new delta conversion UPS configuration is proposed. In this configuration, under the grid fault conditions, the parallel and series inverters are connected in parallel by using static switches. This leads to effective use of series inverter unbound power, hence both inverters could be the same and consequently the system became modular. Since, capacity of the series inverter is increased by 2.5 time, comparing to conventional delta conversion UPS, the UPS compensation capacity is increased by 2.5 time, too. The given cost analysis shows that reduction in the necessary total capacity of the UPS converters from 120% to 100% of the load power value results the system cost reduction, as well. Also reliability analysis shows that the proposed configuration increases the UPS reliability, too. The given simulation results validate proper operation of the proposed configuration.

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