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ANALYSIS AND RECTIFICATION OF UNWANTED TRIGGERING OF SILICON CONTROLLED RECTIFIER (SCR) IN ONLINE UNINTERRUPTIBLE POWER SUPPLY

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Abstract - Uninterruptible Power Supplies (UPS) are the system that is used to provide power back-up when the electricity fails. In Online UPS System, when the power is returned after failure, it changes from battery mode to online/normal mode. During this time an unwanted signal or noise is generated in the bypass path of the system. This signal causes the triggering of Silicon Controlled Rectifiers (SCRs) present in the Static Bypass Switch. Such a thyristor triggering can result in short circuit. It is also associated with large voltage and large current which results in huge power loss and thus the device may end up being damaged. In order to avoid this, a contactor circuit has been proposed. The usage of contactor in the circuit reduces the noise level and increases the efficiency of the system by 96%. Thus, we can use the UPS uninterruptedly in various areas without any distortions.

KEYWORDS: silicon-controlled rectifier [SCR]; static bypass switch; triggering; short circuit; contactor; distortion; noise; online UPS; power; efficiency.

1. INTRODUCTION

An Uninterruptible Power Supply or an UPS is an electrical apparatus that is used to deliver emergency power to the load when the input power or main power fails (Y. Dong et al., 2023). UPS is typically used in computers, data centres, telecommunication equipment and electrical equipment. It protects the hardware in case of power disruptions, small power surges, line sags, long power outages etc (Srikar Sreenath Bharadwaj et al., 2021). It is very important to have a reliable UPS in cases where power failure occur frequently in order to avoid data loss and equipment damages (Chrysostomou et al., 2021). For example, in healthcare industry safety of the patient's health rely on medical equipment that has reliable power supply with clean and unceasing power (Stawowy et al., 2021). The UPS topology consists of three types: Online, Offline and line interactive UPS (Rajani GN, 2016).

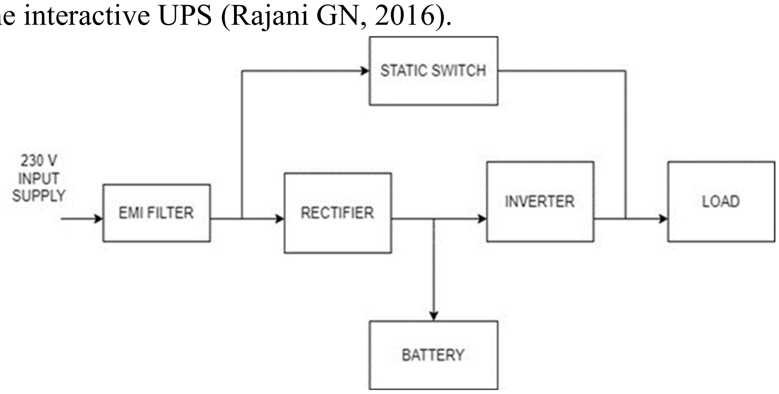

Fig 1. Block Diagram of Online UPS

In offline UPS the power supply has two separate paths. One path works during normal operation and the other path works during power failure. During normal operation the power from AC mains is supplied directly to output. During power failure the load draws power from the battery. These two lines form the supply lines. The changing of power from one source to another during a power outage is called switching. Switching occurs by a duration of 5ms. But, for sensitive devices like hospital ICUs this switching is not considered efficient. It might cause the device to shut down. So, to prevent these online systems were invented

The operation of Online UPS systems involves taking input from the AC mains and passing it through a rectifier and inverter to provide continuous power supply to mission critical appliances. In the event of a power failure, the system switches to battery mode to maintain power supply to the load (William A. Venturini et al., 2015). A block diagram of the system is shown in Fig.1.However, during the changeover from normal mode to battery mode, there is a possibility of an unwanted triggering of the Silicon Controlled Rectifier (SCR) present in the Static Transfer Switch. This can generate a random signal on the bypass path, while another output signal passes through the UPS path. These two signals may differ in phase, and when combined at the load, can cause a short circuit. In order to reduce the distortions in Online UPS various methods including Spike Suppressor/Surge Protector and Radio Frequency filter/EMI filter are studied. Various researches are carried out to resolve distortions and improve the dynamic responses in UPS systems. These systems can improve the stability by increasing filter capacitance and control frequencies. An effective solution provides reduced voltage distortion, transient error and steady state error (T. F. Wu et al., 2022). The UPS should also have lower harmonic distortion with high power factor (Balal et al., 2021).

Spike Suppressor is an electrical device designed to protect the UPS from voltage spikes. The spike suppressor protect device from voltage spikes but not gives a guarantee protection against all electrical damage. Some high energy spikes still damage the equipment despite the protection of a spike suppressor. Giuntini et al., (2012) discussed about Surge Protection devices (SPD) associated with online UPS. It protects the system from voltage spike and transients by attenuating the residual voltage. For example, the UPS may be subjected to lightning surges that causes impulse signals in microseconds range but involving high frequencies and disrupt normal functioning of UPS. In High efficiency operation mode called advanced ECO mode, SPD can reduce surges up to 30% above the peak voltage for less than 1ms. However, these devices might add additional cost to the system.

Radio Frequency or Electromagnetic Interference (EMI) filters are used to either accept or reject signals within a particular radio spectrum, typically ranging from 30Hz to 300Hz. The required frequency for such filters is usually 60Hz (Tiago J. L et.al, 2002). However, one major limitation of this method is that the filter allows all frequencies to pass through, albeit with varying degrees of attenuation. Therefore, it is essential to select an appropriate RF filter that can attenuate undesired frequencies to the required level to enable proper system functionality. By choosing the right RF filter can be challenging and time-consuming, as it requires costly software to perform simulations and manual tuning. To ensure optimum performance of the filter, it is imperative to identify the frequencies that are causing interference and select a filter that can attenuate these frequencies effectively. Additionally, it is essential to consider factors such as filter insertion loss, passband ripple, and stopband attenuation when selecting an RF filter. RF filters are critical components in modern communication systems, and the selection of the appropriate filter is crucial for ensuring reliable and efficient system performance. Despite the challenges associated with choosing the right filter, advancements in technology have led to the development of more efficient and cost-effective solutions for RF filtering.

EMI /RF filter can protect equipment from leakage current. Leakage current is the current that flows to components in the system due to the absence of proper grounding. M Riduan B et al. (2014) proposed an Earthing current Signature Analysis (ECSA) helps to determine the earth leakage current produced by EMI filter. Electromagnetic Interference filter present may produce unintentional capacitance from capacitors present in EMI filters. They produce AC leakage current which will decrease the efficiency of the system. There are high chances that the leakage current may trigger the residual devices. The ECSA technique helps to evaluate the leakage current and helps to track and analyse the root cause. It takes into consideration earthing current waveforms observed. But this filter requires expensive software to perform simulation and manual tuning which is time consuming. Modern online UPS systems used in industrial applications uses three-phase uninterruptible power supply for high-power applications (Ashish kumar Lodhwal et al., 2018). The distortions present in the bypass path occurs during the four-pole changeover in the three-phase online UPS System. It can be corrected considering parameters like voltage, current and power and designing a system to block the current reaching the SCR in accordance with these values. When the silicon-controlled rectifiers are prevented from triggering, no noise signal will be generated in the bypass path (Ambra Sannino, 2001; C.N Lin, 2021; Pere Andrada, 2007; Tahir Mohammed, 2007).

The present paper introduces a novel approach to avert the occurrence of undesired triggering signals from reaching the SCR by utilizing a contactor. The placement of the contactor is positioned between the Static Transfer Switch and the main power supply. In particular, the SCR is prone to trigger when the UPS shifts from battery mode to normal mode. To prevent this, the controller commands the contactor to remain in an OPEN state during this time frame. This setup effectively blocks any current from passing through the bypass path, thereby achieving the elimination of the undesired distortion. The resulting system performance is notably improved, with an efficiency gain of up to 96%.

2. PROPOSED WORK

The proposed study focuses on the application of a contactor to eliminate the triggering signal in the bypass path. A contactor is an electrical switch used to control and switch electrical power circuits, typically in applications that require a higher current carrying capacity. Energizing the contactor coil results in the ordinarily open contacts closing, providing operating power to the load.

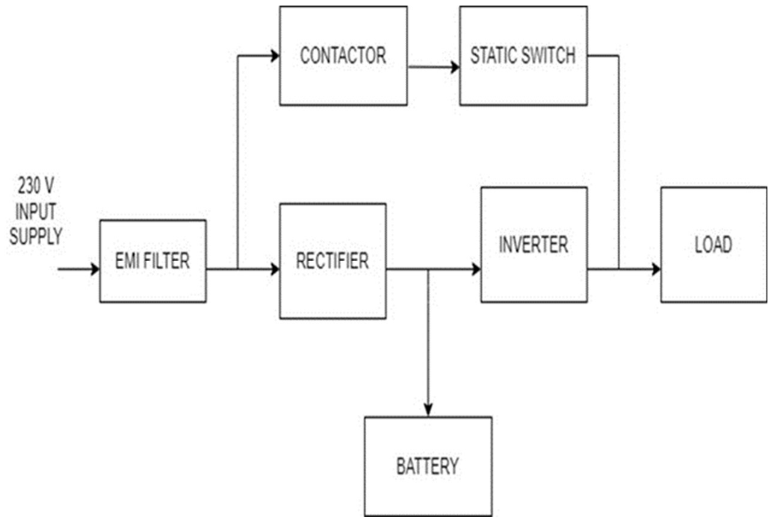

Fig 2. Block Diagram of Online UPS with Contactor

The contactor is initially placed between the static bypass switch and mains supply as shown in Fig. 2. Static bypass switch is common characteristics present in Online UPS (Ashok Kulkarni, 2011). It acts as a protective device in case there is any failure within the UPS system which includes current or voltage overload, internal failure or for maintenance work. Static Bypass switch provides power continuity during occurrence of failure within UPS System. In case of UPS faults the bypass switch automatically connects the load to the main supply. It bypasses the UPS unit that consists of a rectifier, battery and inverter. Hence, the name static bypass switch. It is in turn connected to a Static Transfer Switch PCB or STS PCB (Mohammad Faisal et al., 2020). This PCB is responsible for providing various control signals in the bypass path. The fire signal from the main UPS control circuitry is also given as input to the STS PCB that provides control signals to turn the static switch on and off. The triggering is said to occur during the time of shifting from bypass to online mode. During this time the contactor is controlled by a controller to stay in OPEN state. So, no current passes through the bypass path. Fig 3. shows the contactor used in the project and its specification is listed in Table 1.

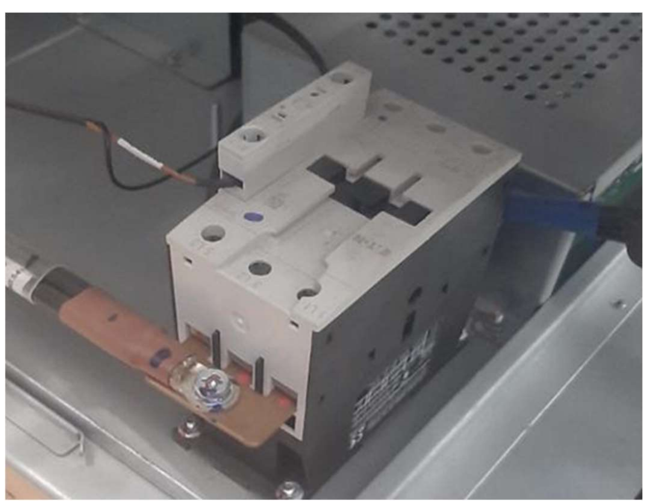

Fig 3. Contactor

Table 1. Contactor Specifications

INPUT VOLTAGE	220-240V
FREQUENCY	50/60 Hz
CONTACTS	2 NC,2 N0
AUXILLIARYCONTACTS	Placed externally as per need

An electromagnetic field is produced whenever the current passes through the electromagnet in the contactor. The moving contact of the contactor is connected with the armature. The electromagnetic field causes the armature to experience a force. This force causes it to pull towards the fixed contact. This magnitude of this force is more than force of the spring. The electromagnet and armature get in contact with each other. Similarly, the movable contact and the fixed contact get connected to each other. The contacts remain in position until the coil is not de-energized and the contactor will be in ON position.

When the coil is de-energized, there will be no electromagnetic field around the armature. The force of spring is more than the armature and it is pulled back. Thus, they are disconnected, which indicates the OFF position. This is the basic operation of a contactor as shown in Fig. 4.

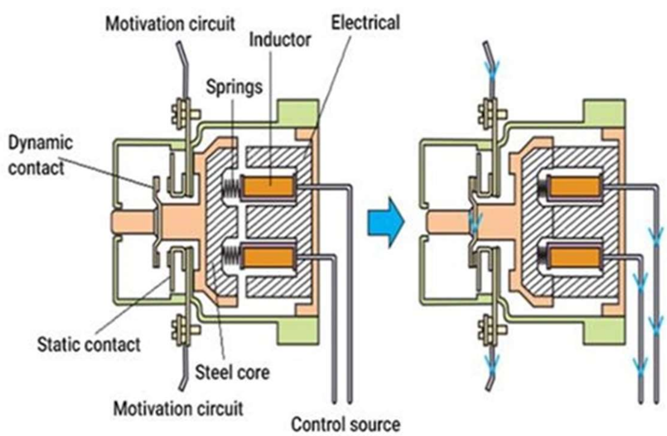

Fig 4: General Working of the Contactor

The contactor system was connected to the testbench and output was observed using oscilloscope. Various modes were also tested to check the functionality of the circuit when the contactor was placed. These modes include online to battery, online to bypass and bypass to online mode. Fig 5 depicts the hardware connection of contactor in real time with Online UPS system. In order to verify the functionality of proposed idea it is very essential to determine performance parameters in the circuit. It helps to analyse the circuit and draw conclusions from them. Efficiency is considered as the major parameter in this project to investigate the performance. The power electronics work at rated-power output level and hence by calculating the input power and output power, efficiency is calculated.

Efficiency is taken into account mainly because of two reasons which include cost and reliability (M. Milad and M. Darwish, 2015). When efficiency is higher, there is less power dissipation. The thermal losses are reduced. Thus, the system requires less expensive silicon devices and thermal management materials such as heat sink, thermal interface etc. For example, consider a high-power converter. Even a few percent of better efficiency in the circuit will result in huge power savings in both device and expenditure. When the efficiency is higher the operating temperature of active and passive devices in the circuit will improve. It will improve the overall reliability of the system.

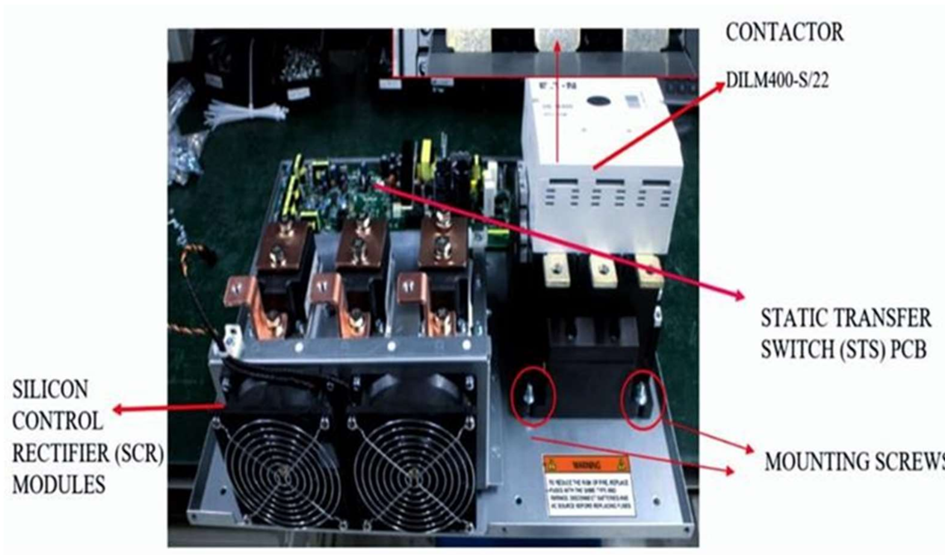

Fig 5. Real Connection of Contactor in Online UPS

3. RESULTS AND DISCUSSION

The simulation results are obtained by connecting the components of the hardware setup to the oscilloscope. The experimental set up used for the implementation mainly includes 100-200 kVA three-phase Online UPS, oscilloscope and power supply. The system is connected to MSO56-350 which is a six-channel oscilloscope that offers high definition and bandwidth. Fig 6. shows the initial noise waveform generated which causes the triggering of SCR in the bypass path in the oscilloscope view.

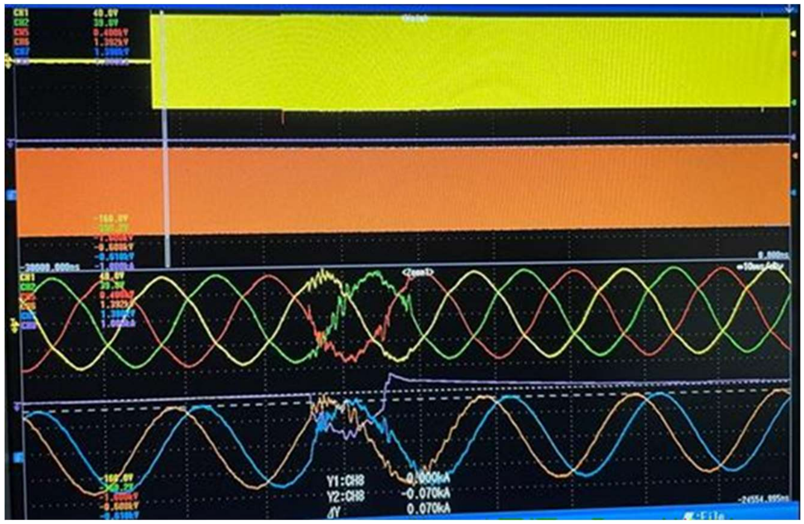

Fig 6. The noise waveform generated in bypass path

In Fig. 6 the noise waveform can be recognized by the distortions appearing in the sinusoidal wave. Channel 1 (CH1) indicates the shifting of the UPS system from battery mode to online mode indicated in yellow colour. It is the input voltage given to the system to operate the UPS in online mode. Channel 5 (CH2) shows the output voltage of the load indicated in orange colour. The three-phase input voltage is shown in the channel 2 (CH3), channel 3 (CH 3) and channel 4 (CH 4). A vertical line is extended from channel 1 to channel 3 represents the exact instant at which the distortion waveform is observed. The Channel 6 (CH6) indicates the variation in current observed during the switching. It is observed that during switching the circuit follows proper voltage and current level but after a few milliseconds noise is generated. The spikes in the oscilloscope output represents the error signal. This error signal is considered as the cause of unwanted triggering of SCR. This condition occurs unfrequently and unevenly. But, still produces undesirable effects at times.

Initially, we consider the output waveform obtained before placing the contactor which is depicted in Fig 7. The figure shows the output obtained from oscilloscope and it is taken as Scenario 1. In this scenario it can be observed that Channel 4 (CH4) and Channel 5 (CH5) represents the sinusoidal waves of voltage and current flowing through the bypass line which are represented by blue and red lines respectively. There is phase difference between the current and voltage value due to the triggering signal. At the same time, we can observe distortions produced in the three-phase input line as a result of the triggering. It is depicted by Channel 1 (CH1), Channel 2 (CH2) and Channel 3 (CH3) represented by yellow, green and violet lines respectively.

Scenario 2 considers the output waveform obtained after placing the contactor and it is shown by Fig. 8. The contactor is kept open for 5-10s depending on the UPS system used. The triggering signal will be not allowed to pass to the SCR present in static switch as the contactor operation will make the circuit open. It is observed that the output voltage and current generated is in-phase and less distortions are seen depicted by red and blue waves as above. The three-phase output voltage generated is also having most minimal distortions. These sinusoidal waveforms produced presents very small total harmonic distortion. Thus, the output waveform through the bypass path produces corrected output.

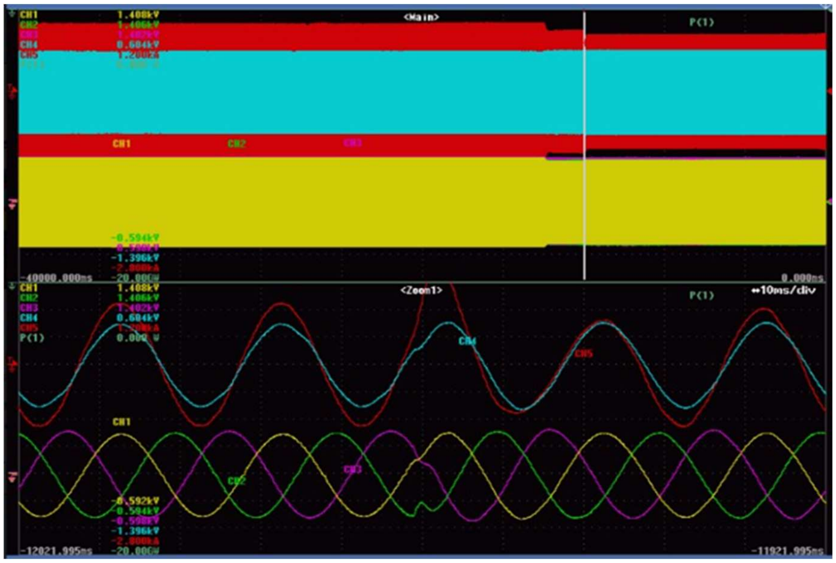

Fig 7. Waveform obtained without Contactor

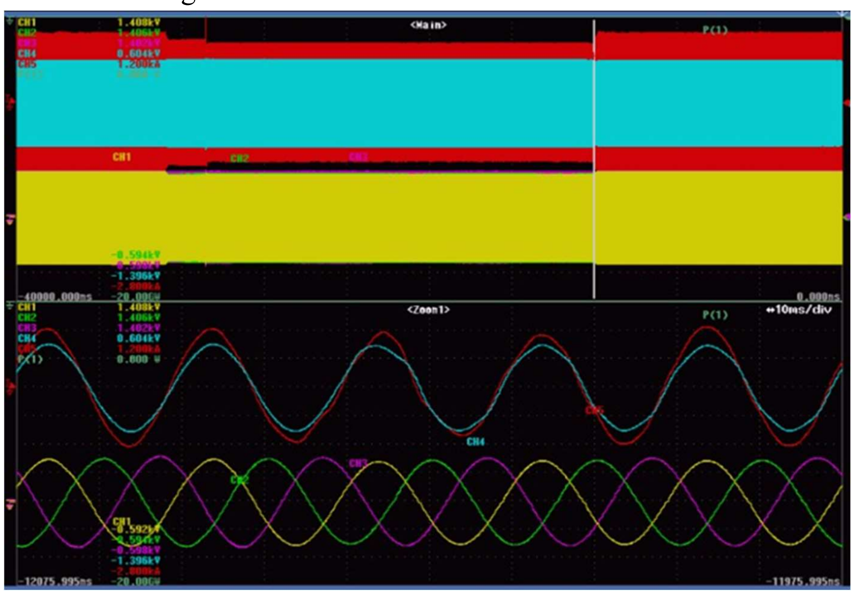

Fig 8. Waveform obtained with Contactor

The parameter used to check the accuracy of the proposed method is efficiency. Efficiency is the ratio of total output power to input power and expressed in percentage and thus it has no unit. Its formula is as follows:

$$\eta=\frac{P_{out}}{P_{in}}X100\% \quad (1)$$

Table 2. Performance of UPS without Contactor

INPUT POWER(kW)	OUTPUT POWER					η
187.956		Line1	Line2	Line3	TOTAL	93%
	kW	57.8	58.8	57.6	174.2	
	kVA	58	59.3	58.5	175.8	
	kVAR	0.2	0.5	0.9	2.6	
	PF	0.99	0.99	0.98	0.99	

Table 3. Performance of UPS with Contactor

INPUT POWER(kW)	OUTPUT POWER					η
187.956		Line1	Line2	Line3	TOTAL	96%
	kW	59.8	59.9	59.9	179.6	
	kVA	59.7	59.8	59.7	179.2	
	kVAR	0.1	0.1	0.2	0.4	
	PF	1.00	1.00	1.00	1.00	

Table 2 and Table 3 gives the readings of power taken with and without the contactor. The input voltage given to the online UPS system is 187.956 kW. The output power is taken across line 1 (L1), line 2 (L2) and line 3 (L3) of three phase output line whose values are noted 59.8,59.9 and 59.9 (all in kW) respectively after placing the contactor. The total output power is the sum of the voltage across the three lines. The formula for total power consumption in a three-phase system is indicated using the following formula:

$$P = P_R + P_Y + P_B \tag{2}$$

The output power is given in two units which are kW and kVA. kW represents the amount power converted into useful or working output. It indicates the actual power that is delivered to the system. kVA represents the apparent power which indicates total amount of power to be utilized by the overall system. In a 100% efficient system kW is equal to kVA. The power factor is used to convert kVA to kW, that is convert apparent power to actual power. It is the ratio of Active power(kW) to Apparent Power(kVA). The formula for converting kVA into kW is as follows:

$$\text{Apparent power (kVA) x power factor (pf) = actual power (kW)} \quad (3)$$

kVAR value is also given in the Table 2 and Table 3. kVAR is the measure of reactive power in the system. It is the unused power or the power that has not been converted to kVA. This is the result of the reactive components present in the generator. It is the power responsible for generating the magnetic field in the system. The relation between apparent power (kVA), active power (kW) and reactive power (kVAR) are as follows:

$$kVA = kW + kVAR \quad (4)$$

With the help of the equations above we will calculate and note the value of actual power (kW), apparent power (kVA), reactive power(kVAR), power factor and efficiency. The efficiency is calculated as 0.95553, which is approximately 96%. The calculation done before placing the contactor gives 93% efficiency. There is increase in the value of efficiency of the system. The power factor of the system has also improved. Thus, we can conclude that the system is having 96% efficiency when we use the contactor in the system.
Fig. 9 represents the comparison between output power obtained across the three phase lines, line 1, line 2 and line 3 before and after placing the contactor. The bar chart helps us to understand the variations and improvement in the output power across these lines. The blue colour in the graph indicates the output power before placing the contactor and the orange colour indicates output power observed after placing the contactor. Thus, the proposed control strategy helps to improve the working efficiency and eliminate the total harmonic distortion to the load when the UPS works. It reduces the power loss in the system. The output produced is having high efficiency and stabilize the load voltage. Hence the overall system provides reliable high power quality supply to the AC power grid when the UPS works.

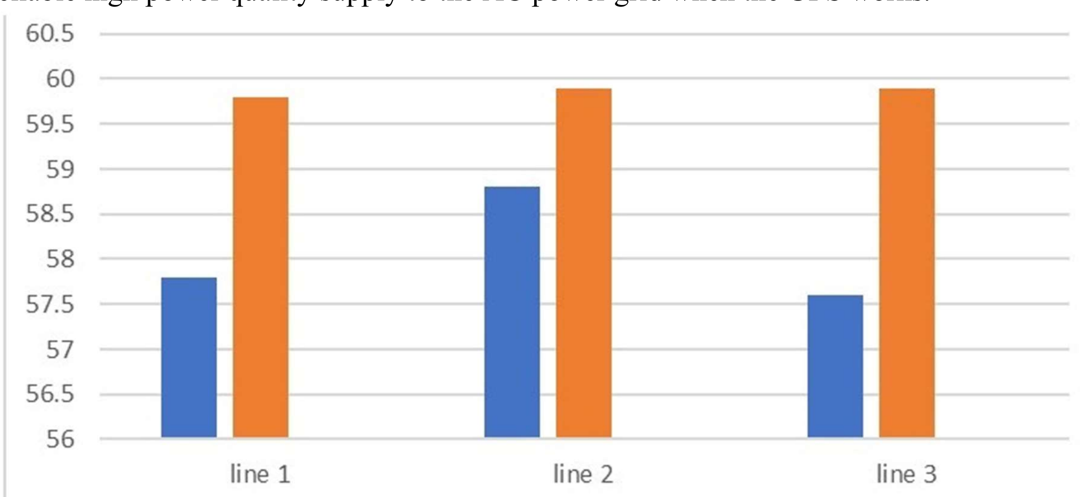

Fig 9. Comparison of output power obtained without Contactor in three-phase output line

4. CONCLUSION

The proposed system using contactor helps us to eliminate the SCR triggering with an overall efficiency of 96%. The power factor of the system has also improved. The proposed method mitigates the short circuit occurrences and surges in the power circuit. The output waveforms produced by the oscilloscope is verified. From the above experiment, it could be understood that the published information on implementation of Contactor is the essential outcome of the project. The various gate driver and SCR protection methods using contactor is also studied. The disadvantages of the existing systems designed by different authors acts as the base for the new proposal. It paves a way for us to come up with a new design and proposal to avoid the damage in power circuits due to unwanted distortions. Hence the proposed method of contactor circuit reduces the noise with an overall efficiency of 96%. The efficiency of the project can be improved by replacing the contactor with PCB level design as this can reduce the overall cost and size of the system. The Contactor increases the overall cost of the system. PCB level circuit design and simulation will provide more efficient and cost-effective solution.

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