International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 6, June - 2014

Simulation of Transformerless Multilevel Series APF based on Improved SRF Theory

Katabathina Venkateswarlu
M.Tech student, Dept. of EEE
Sree vidyanikethan engg. College
Tirupati, India

M. S. Sujatha
Professor, Dept. of EEE
Sree vidyanikethan engg. College,
Tirupati, India

***Abstract*— The nonlinear load in the distribution system rapidly increases, affects the source voltage and damage the sensitive equipment connected at the point of common coupling (PCC). The main aim of this paper is to regulate the source voltage against voltage sag and harmonics by employing transformer less multilevel series active filter based on improved version of synchronous reference frame theory with modified PLL. A cascaded multilevel inverter with separate dc sources has been proposed with carrier shifted sinusoidal pulse width modulation switching method is employed to reduce the harmonic distortion in the output of the inverter. The main advantage of this configuration is no need of injection transformer and reduces the filter requirements. The proposed method is validated through MATLAB/SIMULINK software.**

Key Words: Voltage sag, harmonics, Series active power filter, Cascaded multi-level inverter, Synchronous reference frame theory, Sinusoidal PWM, Modified PLL, Non linear load, MATLAB/SIMULK

I. INRODUCTION

The power quality becomes very important issue because of rapid growth of nonlinear loads. The recent advancements in power electronics leads to saving of energy, cost, operation and control of equipment but at the same time the generation of harmonics affect the source voltage as well as the sensitive equipment connected at the point of common coupling (PCC). So the source needs to supply the harmonic component along with fundamental component this leads to additional generation cost and the high magnitude of currents damages the windings of motors, transformers and other equipments, etc.

The depreciation of voltage from the nominal voltage is called sag or voltage dip typically voltage lies between 0.2 to 0.9 pu. In the recent year the loss of production due to voltage sag is very high and severe stress on the equipment insulation and many problems arises due to insulation failures. Swell is the excess amount voltage typically lies between 1.2 to 1.9pu of the nominal voltage. However these are less dominant compared sag. Now a days the recent advances in power electronics makes the use of nonlinear loads are rapidly increases. This affects the source voltage as well sensitive equipment connected at the point of common coupling. There many other PQ problems like transients, flickers, notches etc. but voltage sag and harmonics are dominant in present power system.

There are many solutions are available to protect the voltage at PCC like DVR, D-STATCOM, shunt active filter, series active filter, UPQC etc. The proposed series active power filter is a series compensating device. It acts as a controlled voltage source and can compensate all voltage-related problems, such as voltage harmonics, voltage sag, voltage swell, flicker, etc at the source side of distribution system. The multilevel inverter has been proposed and it has an advantage of low harmonic distortion. The control mechanism for APF is derived from synchronous reference frame theory. The proposed method is implemented in MATLAB/SIMULINK software.

II. SERIES ACTIVE POWER FILTER

The series APF injects a voltage in series with the supply voltage and reduce harmonic components in voltage waveforms. Therefore series APF can be regarded as harmonic filter. The basic structures of conventional and proposed series APF are shown in fig. 1(a), (b) respectively. Series APF is a voltage source inverter (VSI) with control mechanism of detection of disturbances and generation of required signals. The proposed scheme has an advantage of omission of injection transformers which suffers from magnetic core saturation and other problems and this can be done by the use of cascaded multilevel inverter with separate dc sources. The proposed series APF with fixed dc voltage source makes only real power exchange between the line and the series APF. If we use capacitor as dc source makes reactive exchange between line and series APF. The detailed operation of series APF described in later sections.

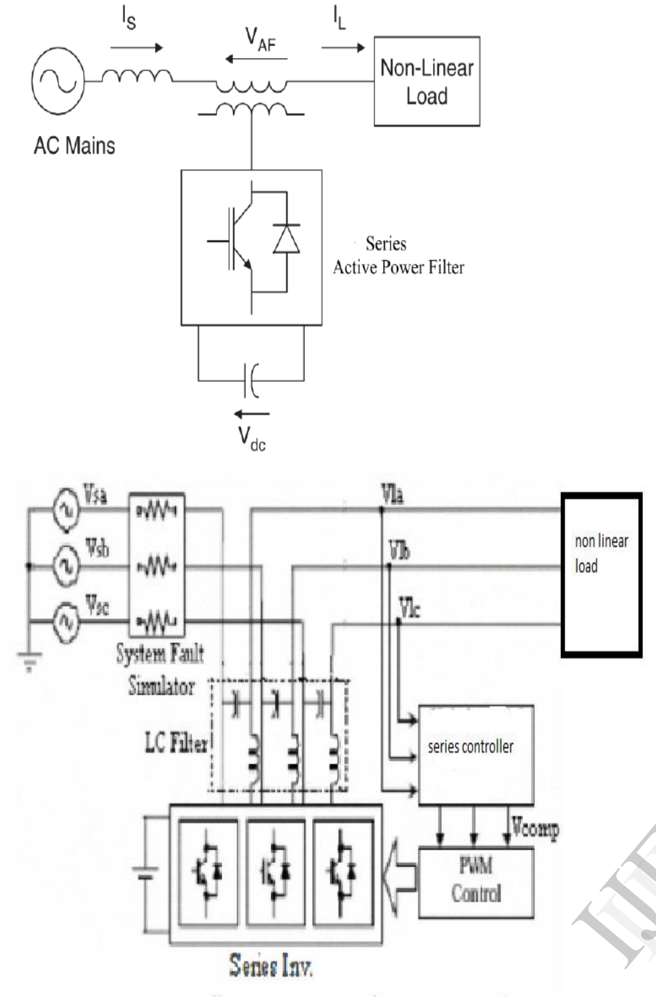


Fig. 1 Series active power filter a) conventional b) proposed.

A. Multilevel inverter

The main advantage of multilevel inverter (MLI) has multiple levels in output waveform i.e. low harmonic distortion in output meets the required power ratings from the availability of power semi conductor devices and also reduced switching stresses on the devices etc. There are three types of MLI are available they are diode clamped, flying capacitor and cascaded multilevel inverters. Among these cascaded MLI has an advantage of circuit flexibility, requires the less number of components among all multilevel converters to achieve the same number of voltage levels, and suitable for inter facing renewable resources to grid and many more.

The structure of cascaded MLI with separate dc sources as shown in Fig. 2.1. To synthesize a multilevel waveform, the ac output of each of the different level H-bridge cells is connected in series. The synthesized voltage waveform is, therefore, the sum of the inverter outputs. The number of output phase voltage levels in a cascaded inverter is defined by $m=2s+1$

here s=number of dc sources, m=number of levels

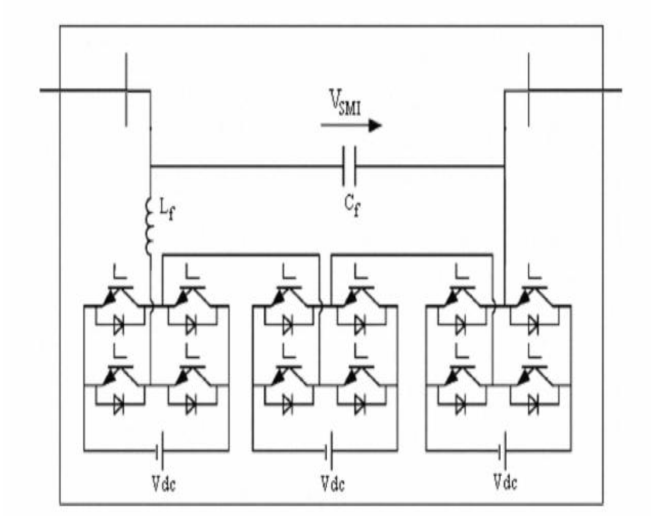


Fig.2.2 The main circuit topology of cascade multilevel series inverter (single phase).

B. Carrier shifted sinusoidal SPWM

A phase-shift sinusoidal pulse width modulation (PS-SPWM) switching scheme is employed to generate pulses for IGBTs of the inverter as shown in fig.2.3

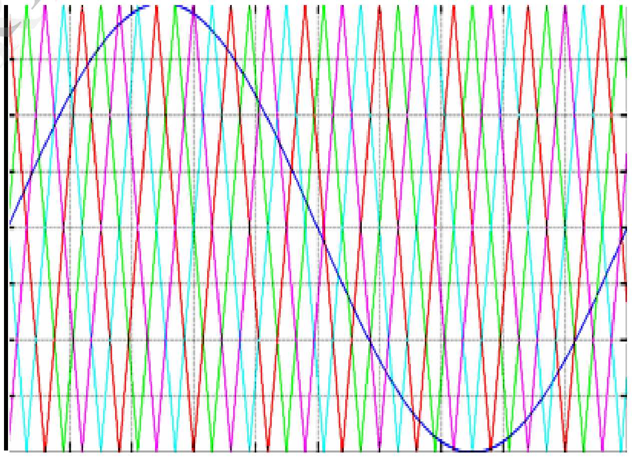


Fig.2.3 Phase Shifted SPWM

Optimum harmonic cancellation is achieved, phase shifting each carrier by

$$(K-1)\ \pi/N,$$

$$N=(L-1)/2$$

Where K is the K^{th} inverter, and N is the number of series-connected single phase inverters, L is the number of switched DC sources.

The output of cascaded MLI with separate dc source based on carrier shifted SPWM switching technique as shown in fig. 2.4

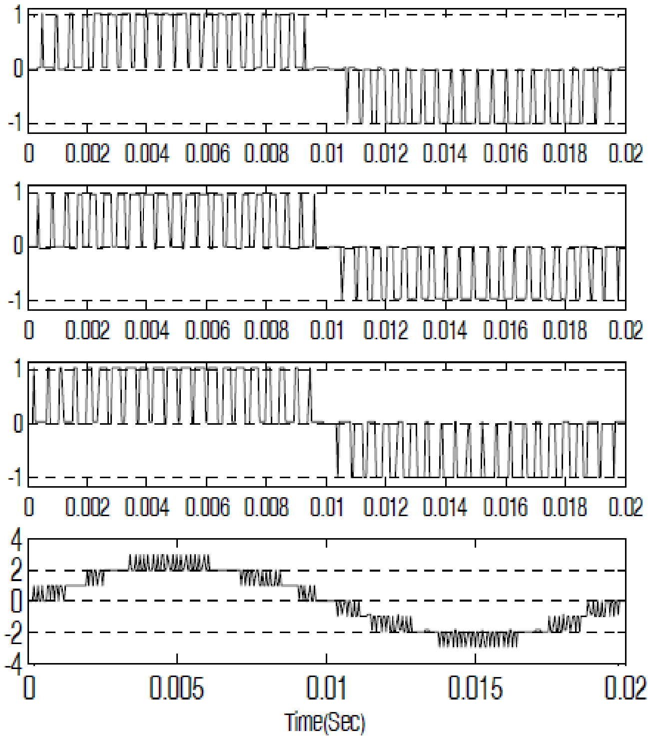


Fig. 2.4 Output of cascaded multilevel inverter with SPWM switching technique.

C. DESIGN OF CONTROLLER

a) Synchronous reference frame theory

Among the several APF control methods presented in the literature, the SRF-based control method is one of the most conventional and the most practical methods. The SRF method presents excellent characteristics but it requires decisive PLL techniques. This paper presents a new technique based on the SRF method using the modified PLL algorithm and compares its performances with that of the conventional SRF method under unbalanced and distorted load conditions. The proposed SRF control method uses *abc* to *dq*0 transformation equations, filters, and the modified PLL algorithm shown in Fig. 2.5. The second order low pass filter (LPF) used to filters the lower order harmonics. The proposed method is simple and easy to implement. Hence, the proposed modified PLL algorithm efficiently improves the performance of the series APF under unbalanced and distorted load conditions.

b) Modified Phase Locked Loop (PLL)

The conventional PLL circuit works properly under nonlinear system voltages. However, a conventional PLL circuit design has low performance for high distorted and unbalanced system voltages. In this paper, the revised PLL circuit shown in Fig. 2.6 this is employed for the detection of the positive sequence components of the system voltage. The reason behind making a correction in conventional PLL is to improve the series APF filtering performance under highly distorted and unbalanced voltage conditions. The modified PLL has better performance compared to that of the conventional PLL, since the output of the modified PLL has a low oscillation under highly distorted and unbalanced system voltage conditions. The output of conventional and modified PLL outputs is shown in fig. 2.7.

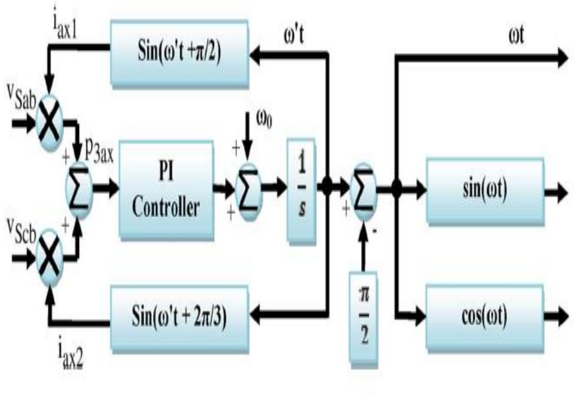


Fig. 2.6 Modified PLL circuit block diagram.

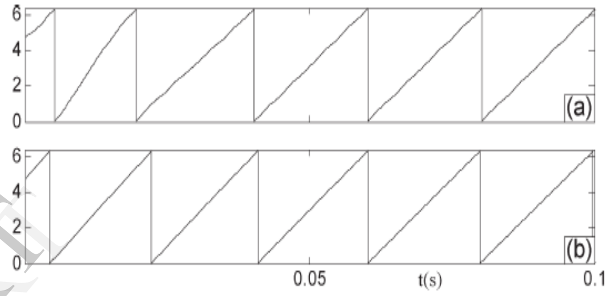


Fig. 2.7. Transformation angle (ωt) waveforms for the a) conventional and b) modified PLL algorithms.

c) Generation of reference voltages

In the proposed method, the series APF controller calculates the reference value to be injected, comparing the positive-sequence component of the source voltages with load-side line voltages. The series APF reference-voltage signal-generation algorithm is shown in Fig. 2.5. In (4), the supply voltages Vsabc are transformed $d-q-0$ by using the transformation matrix T given in (2). In addition, the modified PLL conversion is used for reference voltage calculation.

$$Vsabc=T*Vsdq0$$

$$\begin{matrix} Vs0 \\ Vsd \\ Vsq \end{matrix} = T* \begin{matrix} Vsa \\ Vsb \\ Vsc \end{matrix} \qquad (2)$$

$$T = \begin{matrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ sinwt & \sin(\omega t - 120) & \sin(\omega t + 120) \\ coswt & \cos(\omega t - 120) & \cos(\omega t + 120) \end{matrix} \qquad (3)$$

The instantaneous voltages (Vsd and Vsq) include both oscillating components ($\bar{V}$sd and $\bar{V}$sq) and average components (VSd and VSq) under unbalanced source voltage with harmonics. The oscillating components of Vsd and Vsq contain harmonics and negative sequence components of the source voltages Vs under nonlinear conditions. An average component includes the positive sequence components of the voltages and zero-sequence part (Vs0) of the source voltage occurs when the source voltage is distorted. The source voltage in the direct axis (VSd) given in (5) consists of the average and oscillating components

$$Vsd=\bar{V}sd+\bar{V}sq \qquad (5)$$

The load reference voltages ($V^{'}$ labc) are evaluated as in (6). The inverse transformation matrix $\mathbf{T}^{-1}$ given in (7) is used for generation of the reference load voltages by the average component of source voltage and transformation angle (*ωt)* produced in the revised PLL algorithm. The source-voltage positive-sequence average value (*V*Sd) in the *d*-axis is calculated by low pass filter, as shown in Fig. 2.5. Zero and negative sequence components of source voltage are set to zero in order to compensate source voltage harmonics, unbalance, and distortion, as shown in Fig. 2.5

$$\begin{matrix} V'la \\ V'lb \\ V'lc \end{matrix} = \mathrm{T}^{-1} * \begin{matrix} 0 \\ Vsd \\ 0 \end{matrix} \qquad (6)$$

$$Tinv = \begin{matrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ sinwt & \sin(wt-120) & \sin(wt+120) \\ coswt & \cos(wt-120) & \cos(wt+120) \end{matrix} \qquad (7)$$

The produced load reference voltages (V'La, V'Lb, and V'Lc) and load voltages (VLa, VLb, and VLc) are compared in the sinusoidal pulse width modulation controller to produce switching signals and to compensate all voltage-related problems, such as voltage harmonics, sag, swell, voltage unbalance, etc in the source voltage.

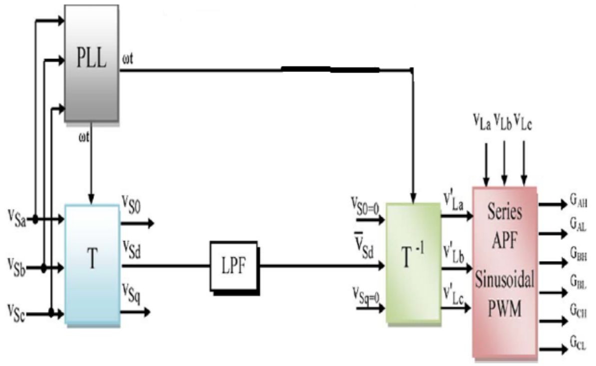


Fig. 2.5 SRF theory based series APF controller

III. SIMULATION STUDY

The performance of the proposed method is analyzed with the help of MATLAB/SIMULINK power system block set. The source voltage of 415V (rms) is connected to the load. Three phase bridge diode rectifier is the source of harmonics and is switch suddenly for the duration of 0.05 to 0.07ms with the help of breaker. The voltage sag of 10% is created during the breaker operation. The series active power filter is connected as shown in figure 1. The simulink modeling of proposed system as shown in fig. 3.1

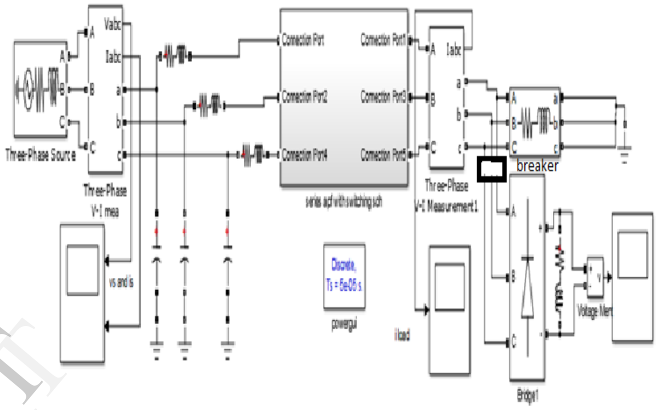


Fig. 3.1 Simulink modeling of proposed system.

The circuit parameters of the proposed method as shown in table 1.

TABLE 1 circuit parameters

S. NO	Component	Specification
1	Source voltage (VS)	415V
2	Frequency (f)	50HZ
3	Number of H bridges	2 (5-level,Vdc=100V)
4	Linear load	100Ω, 1mH
5	Rectifier load	50 Ω, 30mH
6	Filter inductance(Lf) Capacitance(Cf) Resistance(Rf)	30mH 0.1µF 100Ω

The voltage sag due to sudden switching of load (non linear load) and the switching load is nonlinear load generates harmonics. The source voltage before and after applying series compensation analyzed as shown in fig. 3.4.

The simulink modelling of cascaded multi level inverter is shown in fig. 3.2.

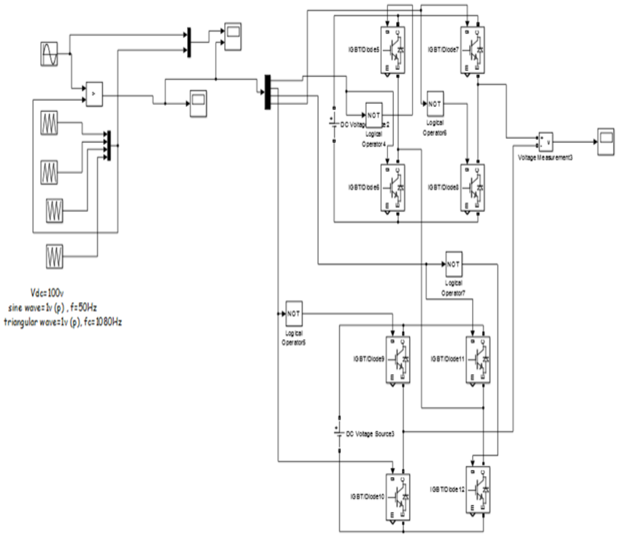


Fig. 3.2 Cascaded MLI with SPWM technique.

Simulink modeling of proposed SRF theory based series APF controller with modified PLL. As shown in fig. 3.3

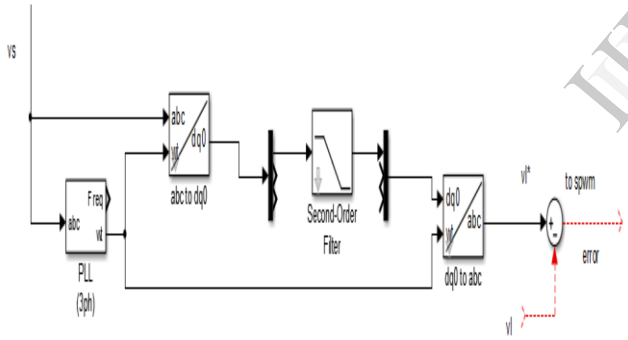
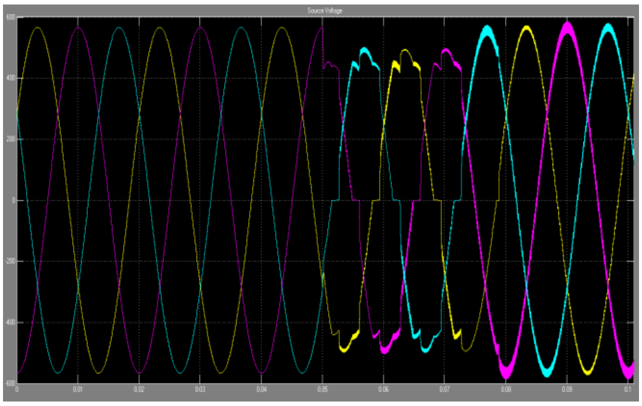


Fig. 3.3 simulink model of SRF theory based series APF controller.



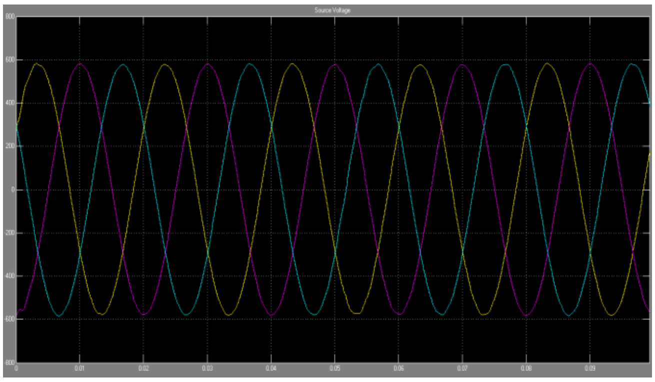


Fig.3.4 Source voltage a) before compensation b) after compensation.

The voltage sag of 10% of rated voltage is compensated as shown in fig. 3.4. The harmonic analysis (FET analysis) can be done with the help of powergui block before and after applying compensation shown in fig.12. The source voltage before compensation has THD about 9.8%. After applying series APF the THD in source voltage is about 0.54%. These results make the performance of series APF under voltage sag and harmonics.

The use of filter is optional based on the tolerance levels according to standards IEEE-519 1992. The advantage of multilevel inverter makes reduction of the filter requirements.

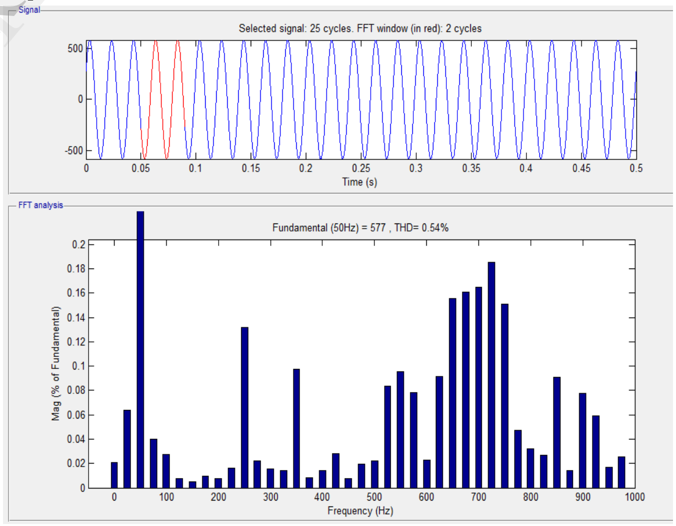


Fig.3.5 FET analysis.

The performance of series APF can be analyzed below

S.NO	Parameter	Before compensation	After compensation
1	Sag	10%	0.1%
2	Harmonics(THD)	9.8%	0.54%

IV.CONCLUSION

The voltage sag and harmonics are important problems in power quality. The performance of series active APF under sudden application of nonlinear load (rectifier load) was analyzed in MATLAB. The synchronous reference frame theory with modified PLL leads to improvement in performance of compensator under voltage unbalanced and distorted conditions. The sag is compensated and the harmonics are reduced from 9.8% to 0.54. Finally the source voltage of the distribution system can be regulated with the help of proposed configuration of the series APF.

REFERENCES

[1] H. Akagi, "New trends in active filters for power conditioning," *IEEE Trans. Ind. Applicat.*, vol. 32, no. 6, pp. 1312–1322, 1996.

[2] N. Farokhnia, S.H. Fathi, H. R Toodeji, "Voltage Sag and Unbalance Mitigation in Distribution Systems Using Multi-level UPQC," IEEE conference on power quality , March 2011.

[3] Mariusz Malinowski, K. Gopakumar, Jose Rodriguez, Marcelo A. Perez, Member, "A Survey on Cascaded Multilevel Inverters," IEEE Trans. on Industrial Electronics, Vol. 57, no. 7, July 2010.

[4] Jose Rodriguez, Jih-Sheng Lai, Fang Zheng Peng, "Multilevel Inverters: A Survey of Topologies, Controls, and Applications," IEEE Trans. on Industrials Electronics, Vol. 49, No.4, August 2002.

[5] H. Fujita and H. Akagi, "The unified power quality conditioner: The integration of series and shunt active filters," IEEE Trans. Power Electron., vol. 13, no. 2, pp. 315-322, Mar. 1998.

[6] M. Bollen and M. Bollen, *Understanding Power Quality Problems: Voltage Sags and Interruptions*. Piscataway, NJ: IEEE Press, 2000.