Power Quality
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Module - 07
Lecture - 25
Active Series Power Filters (contd.)

Welcome to the course on Power Quality. We were discussing the numerical examples on series active filter.

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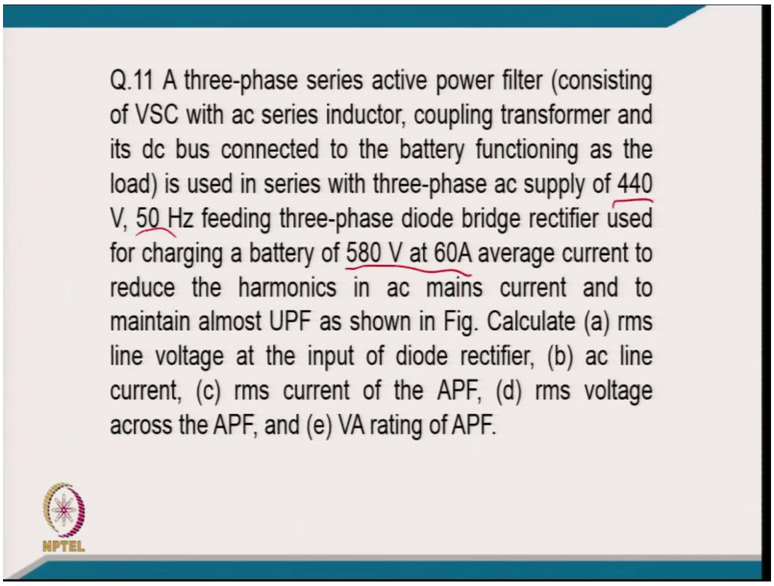

Coming to example number 11, a three-phase series active filter of voltage source converter with ac series inductor, coupling transformer and its dc bus connected to the battery functioning as a load is used in series with the three-phase ac supply of 440 volt, 50 hertz feeding a three-phase diode bridge rectifier used for charging a battery of 580 volt at 60 ampere average current to reduce the harmonics in ac mains current and to maintain almost unity power factor as shown in figure.

Calculate a, the line voltage at the input of diode rectifier a, b, ac line current c, rms current of active power filter d, rms voltage across the active series active filter and the VA rating of series active filter like.

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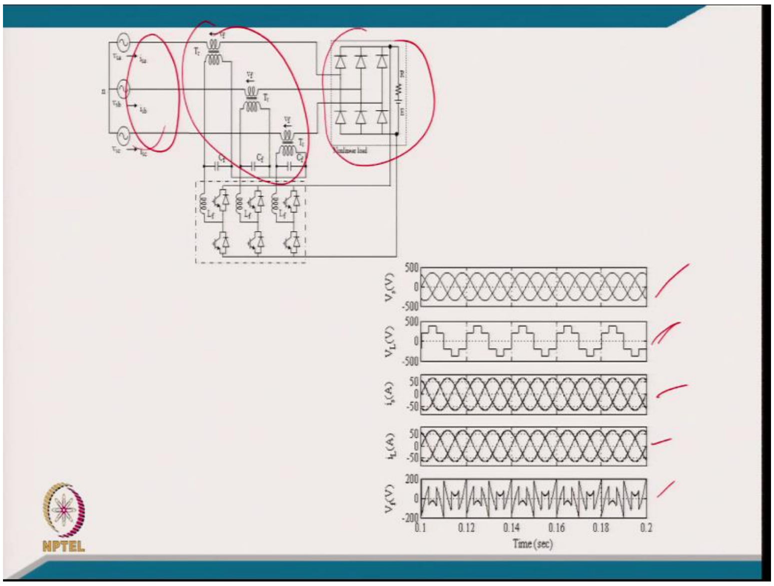

The explanation of the numerical problem is described in the screenshots herein.

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Solution: Given that, supply voltage, $V_s = 440/\sqrt{3} = 254.03V$, frequency of the supply f=50 Hz, V_{dcload}=580V, I_{dc}=60A.

The active power is as, $P = V_{dc} I_{dc} = 580*60$ W=34800 W.

The supply current is as, $I_s = 34800/(3*254.03) = 45.664A$.

The sine wave supply current after the compensation results in continuous conduction of diodes of the three phase diode rectifier (each diode conducting for 180°) and it results in the waveform of the phase voltage at the input of diode (V_{pccph}) is a stepped waveforms as (i) first step of π/3 angle {from 0° to (π/3)} and a magnitude of ($V_{dcload}/3$), (ii) second step of π/3 angle {from (π/3) to (2π/3)} and a magnitude of {$2V_{dcload}/3$}, (iii) third step of π/3 angle {from (2π/3) to (π)} and a magnitude of {$V_{dcload}/3$} and it has both half cycles of symmetric segments of such steps.

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(a) The rms line voltage at the input of diode rectifier is computed as follows.

The sine wave supply current after compensation results in continuous conduction of diodes of the rectifier (180°) and it results in quasi square wave ac voltage at PCC with an amplitude of dc bus voltage, $V_{pcc}=V_{dcload}*(\sqrt{2}/\sqrt{3})=473.57$ V.

Therefore, $V_{pcc}=473.57$ V.

(b) The supply line current at unity power is as,

$I_s=34800/(3*254.03)=45.664A$

(c) The current rating of series APF is as,

$I_f = I_s=45.664A$

(Since APF is connected in series with supply)

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(d) The rms voltage rating of series APF, V_f is computed by taking the difference of the supply phase voltage and phase voltage at the input of diode rectifier as follows.

$$V_f = \sqrt{(1/\pi)\left\{\int_0^{\pi/3}(254\sqrt{2}\sin\theta-193.33)^2 d\theta + \int_{\pi/3}^{2\pi/3}(254\sqrt{2}\sin\theta-386.67)^2 d\theta + \int_{2\pi/3}^{\pi}(254\sqrt{2}\sin\theta-193.33)^2 d\theta\right\}} = 81.4622\ V$$

(e) The kVA rating of VSC of APF is as,

$S=3*V_f*I_s=3*81.4622*45.664$ VA= 11.16 kVA.

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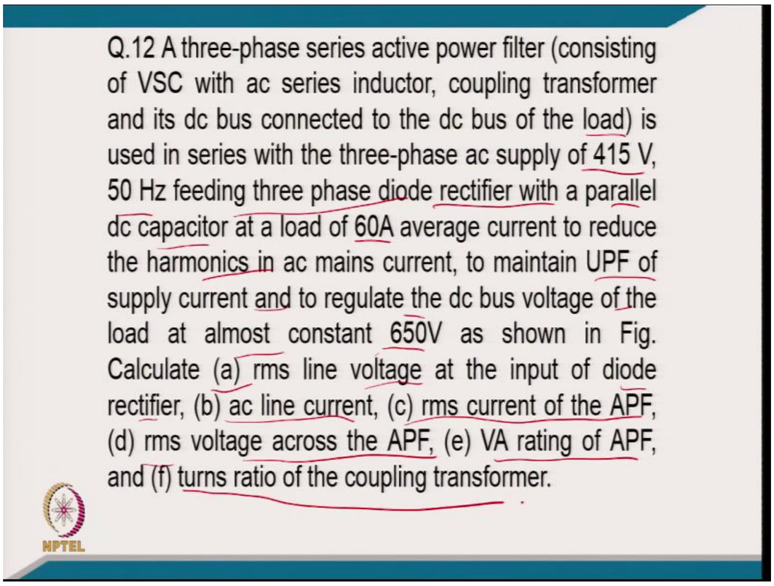

Coming to the numerical problem 12, a three-phase series active power filter consisting of voltage source converter with ac series inductor, coupling transformer and its dc bus connected to the dc bus of the load is used in series with the three-phase supply of 415 volt, 50 hertz feeding a three-phase diode bridge rectifier with a parallel dc capacitor at a load of 60 ampere average current to reduce the harmonics in ac mains current to maintain unity power factor of supply current and to regulate the dc link voltage of the load almost constant at 650 volt as shown in the figure.

Calculate a, rms line voltage at the input of diode bridge rectifier b, the ac line current c, rms current of the active series filter d, the rms voltage across the series active filter e, VA rating of the series active filter and f, the turns ratio of the coupling transformer is used in series active filter.

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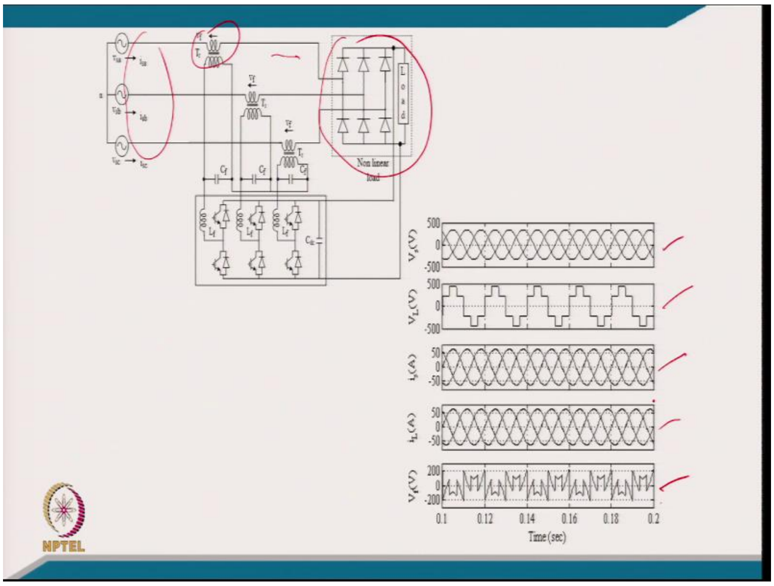

The explanation of the numerical problem is described in the screenshots herein.

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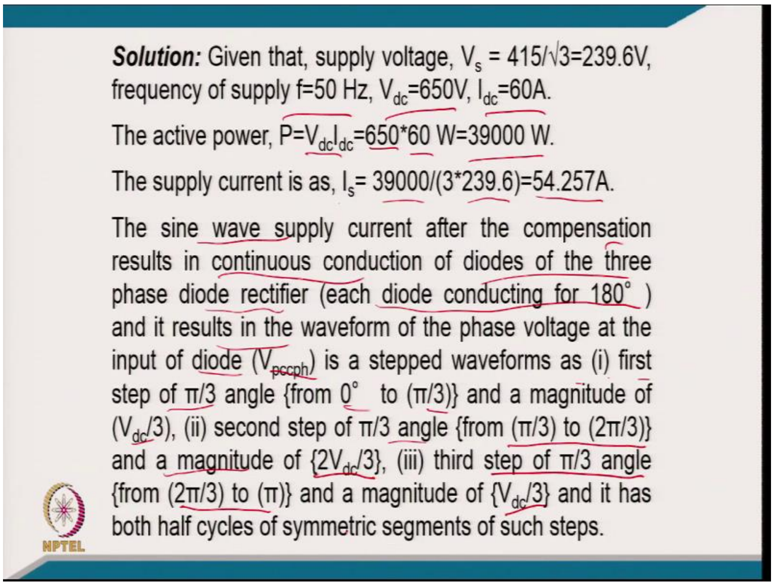

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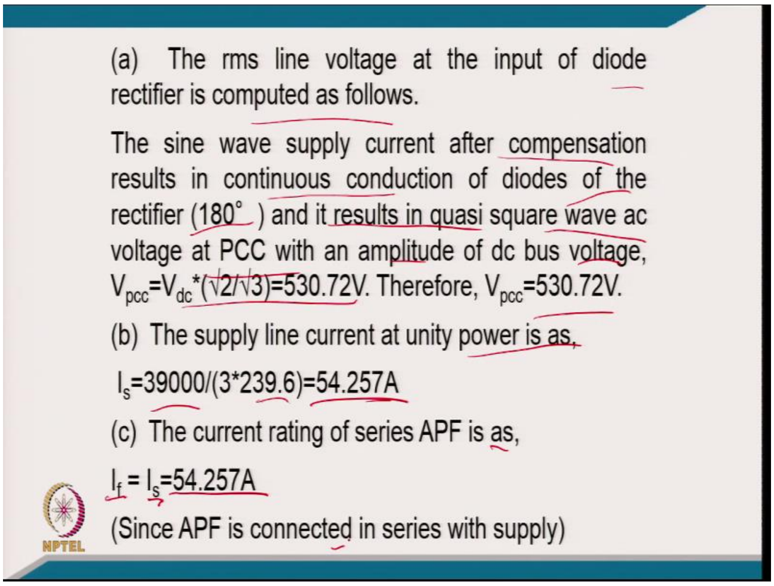

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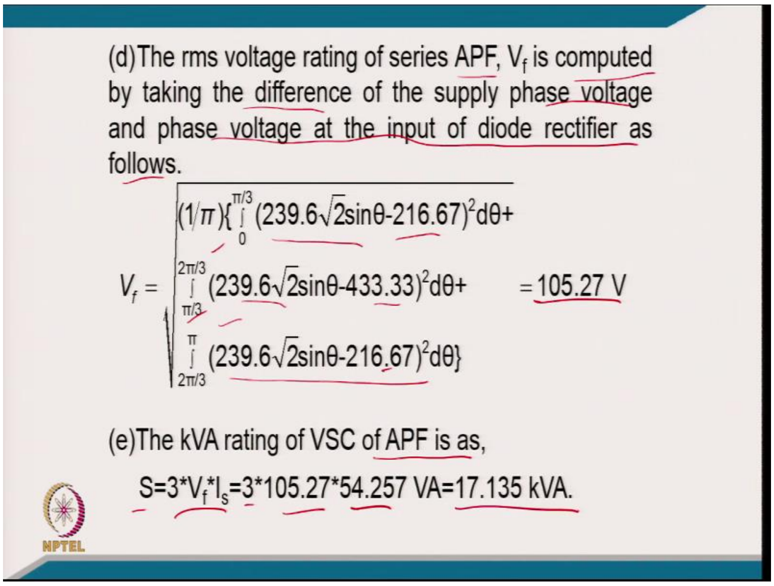

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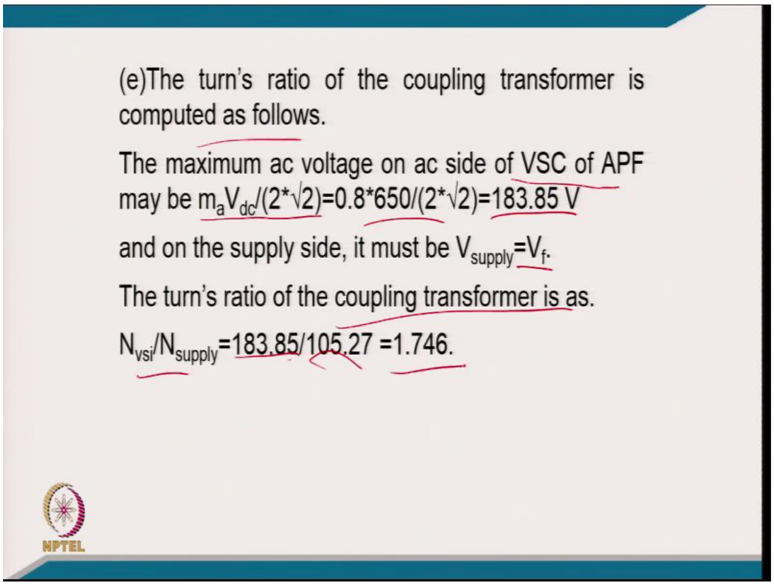

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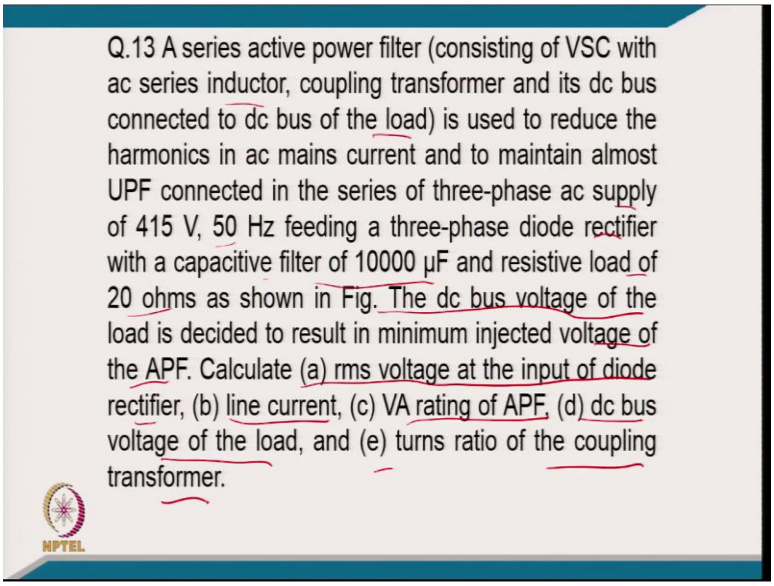

Coming to the 13th example, a series active power filter consisting of voltage source converter with ac series network coupling transformer and it dc bus connected to dc bus of the load is used to reduce the harmonics in ac mains current and to maintain almost unity power factor connected in the series of the three-phase ac supply or 415 volt, 50 hertz feeding a three-phase diode rectifier with the capacitive filter of 10000 microfarad and the resistive load of 20 ohm as shown in the figure.

DCc bus voltage of the load is decided to result in a minimum injected voltage of series active filter. Calculate a, rms voltage at the input of diode rectifier b, the line current c, the volt VA rating of the series active filter d, the dc link voltage of the load and e, the turns ratio of coupling transformer.

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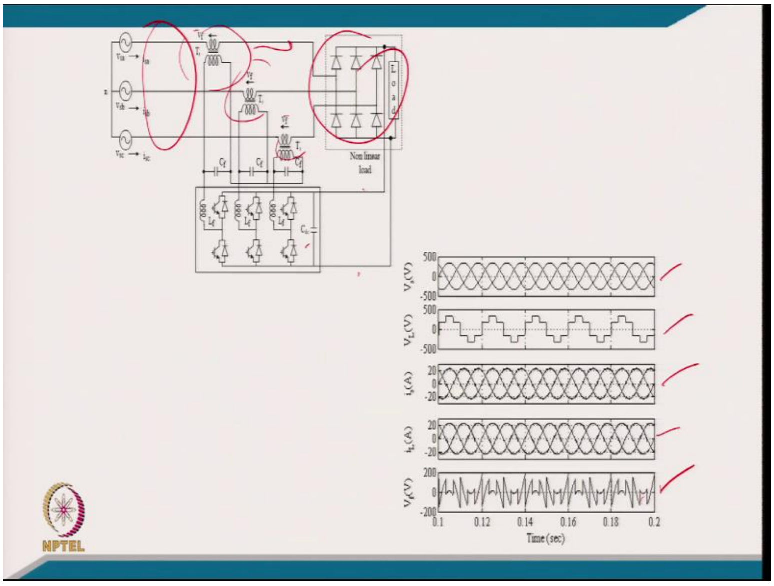

The explanation of the numerical problem is described in the screenshots herein.

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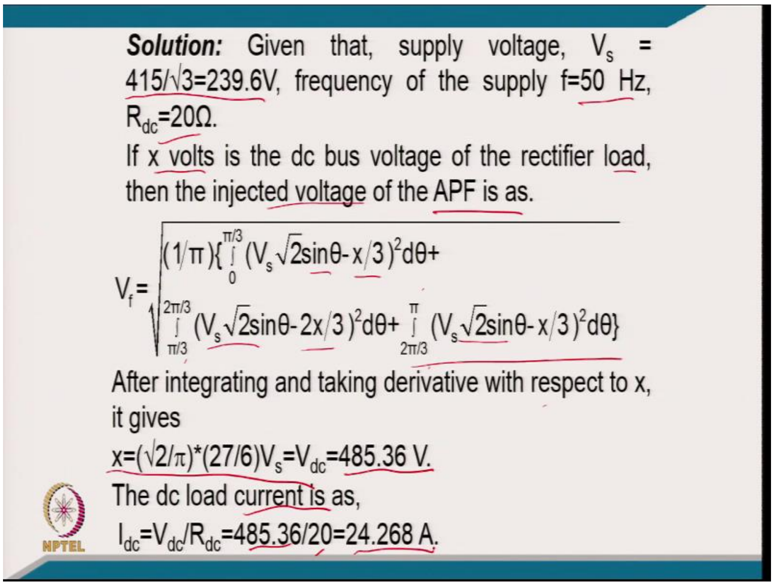

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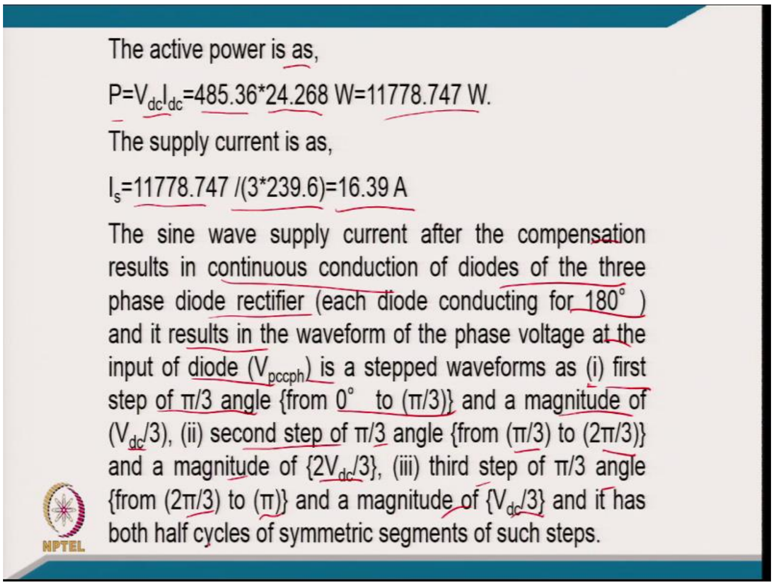

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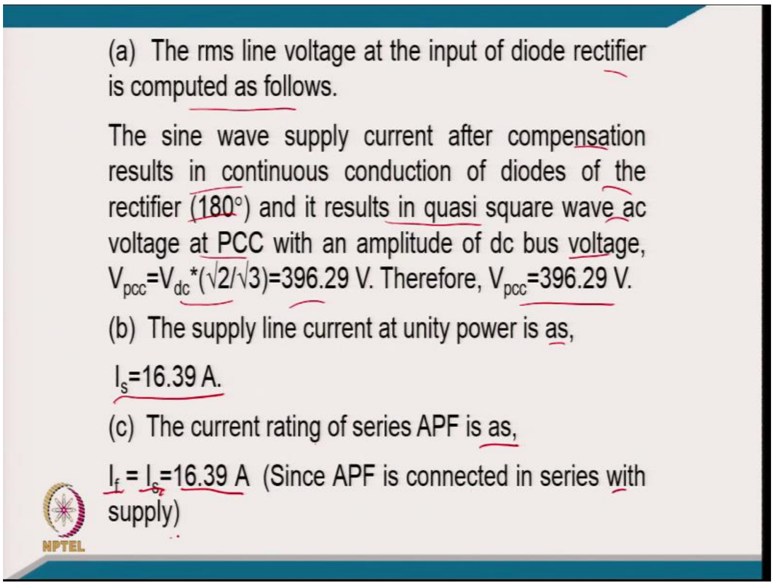

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(d) The rms voltage rating of series APF, V_f is computed by taking the difference of the supply phase voltage and phase voltage at the input of diode rectifier as follows.

$$V_f = \sqrt{\begin{array}{l}(1/\pi)\{\int_0^{\pi/3}(239.6\sqrt{2}\sin\theta-161.79)^2 d\theta+ \\ \int_{\pi/3}^{2\pi/3}(239.6\sqrt{2}\sin\theta-323.57)^2 d\theta+ \\ \int_{2\pi/3}^{\pi}(239.6\sqrt{2}\sin\theta-161.79)^2 d\theta\}\end{array}} = 71.12 \text{ V}$$

(e) The kVA rating of VSC of APF is as,

$S=3*V_f*I_s=3*71.12*16.39$ VA $=3.497$ kVA.

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(e) The turn's ratio of the coupling transformer is computed as follows.

The maximum ac voltage on ac side of VSC of APF may be $m_a V_{dc}/(2*\sqrt{2})=0.8*485.36/(2*\sqrt{2})=137.28$ V

and on the supply side, it must be $V_{supply}=V_f$.

The turn's ratio of the coupling transformer is as.

$N_{vsi}/N_{supply}=137.28/71.12=1.93$.

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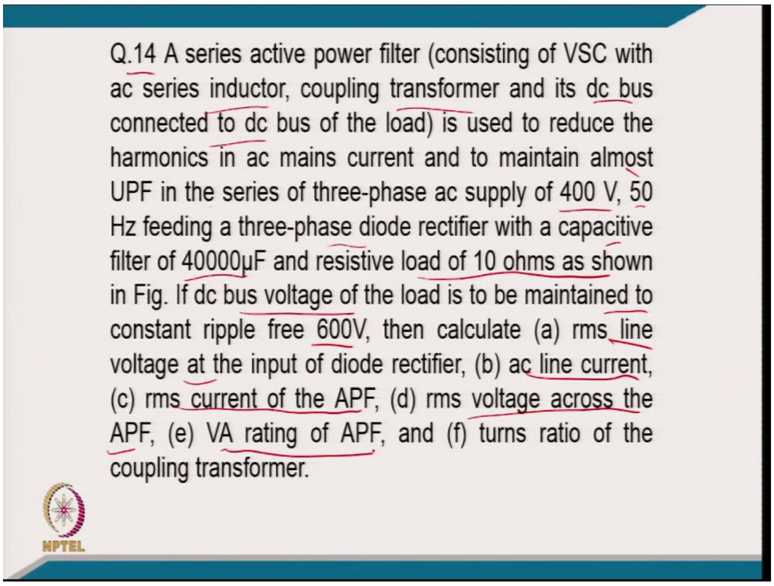

Coming to the problem number 14, a series active power filter consisting of voltage source converter with ac series inductor, coupling transformer and its dc connected to the dc bus of the load is used to reduce the harmonics in ac mains current and to maintain the almost unity power factor in series with the three-phases ac supply of 400 volt, 50 hertz feeding a three-phase diode rectifier with the capacity filter of 40000 microfarad and resistive load of 10 ampere as shown in the figure.

If the dc bus voltage of the load is to be maintained constant ripple free of 600 volt, then calculate the rms line voltage at the input of diode rectifier, ac line current, rms current of the series active filter, rms voltage across the series active filter, VA volt ampere rating of the series active filter and the turns ratio of coupling transformer.

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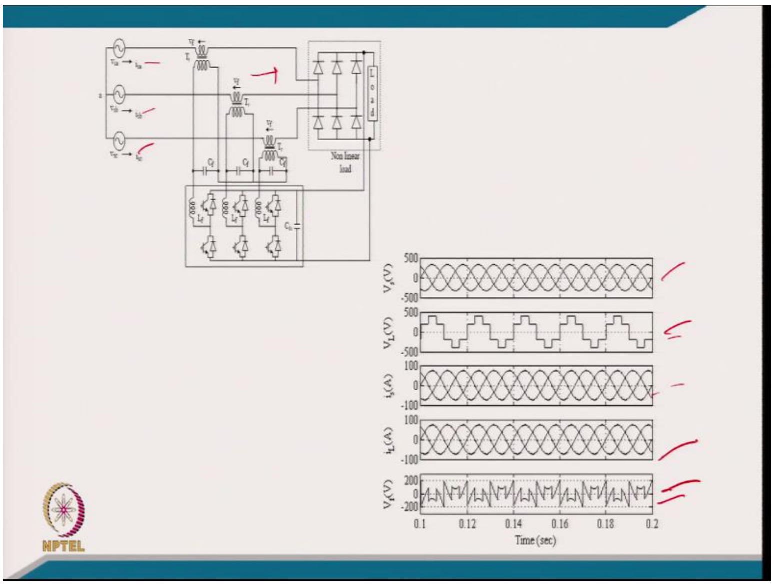

The explanation of the numerical problem is described in the screenshots herein.

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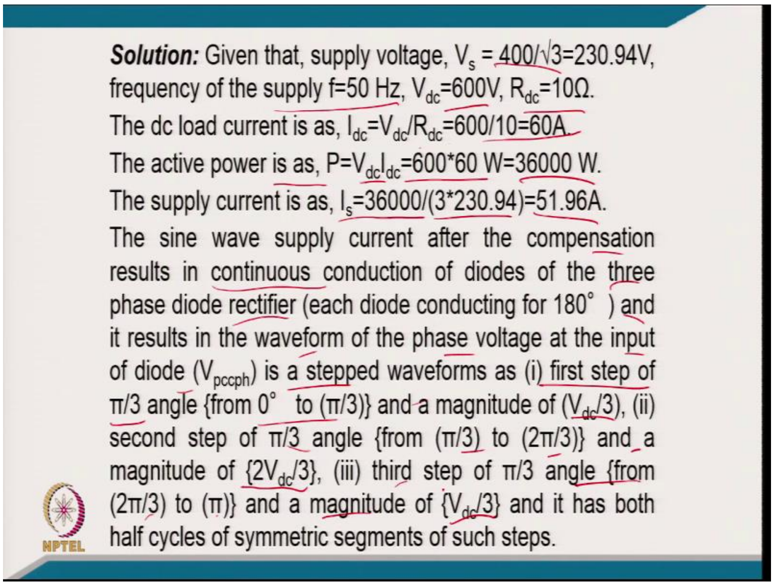

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(a) The rms line voltage at the input of diode rectifier is computed as follows.

The sine wave supply current after compensation results in continuous conduction of diodes of the rectifier (180°) and it results in quasi square wave ac voltage at PCC with an amplitude of dc bus voltage, $V_{pcc}=V_{dcload}*(\sqrt{2}/\sqrt{3})=489.89V$.

Therefore $V_{pcc}= 489.89V$.

(b) The supply line current at unity power is as,

$I_s= I_s=36000/(3*230.94)=51.96A$

(c) The current rating of series APF is as,

$I_f = I_s=51.96A$ (Since APF is connected in series with supply)

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(d)The rms voltage rating of series APF, V_f is computed by taking the difference of the supply phase voltage and phase voltage at the input of diode rectifier as follows.

$$V_f = \sqrt{\begin{aligned}&(1/\pi)\{\int_0^{\pi/3}(230.94\sqrt{2}\sin\theta-200)^2d\theta+\\&\int_{\pi/3}^{2\pi/3}(230.94\sqrt{2}\sin\theta-400)^2d\theta+\\&\int_{2\pi/3}^{\pi}(230.94\sqrt{2}\sin\theta-200)^2d\theta\}\end{aligned}} = 92.6382\text{ V}$$

(e)The kVA rating of VSC of APF is as,

$S=3*V_f*I_s=3*92.6382*51.96\text{ VA}=14.44\text{ kVA}.$

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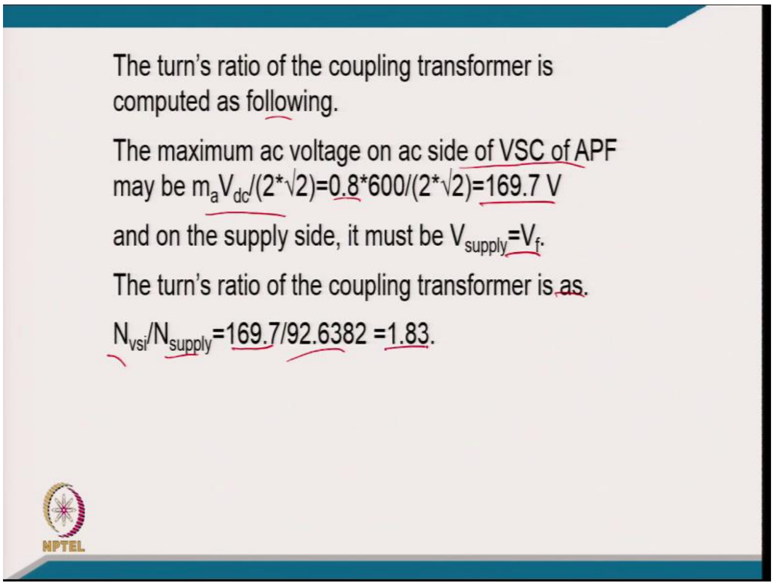

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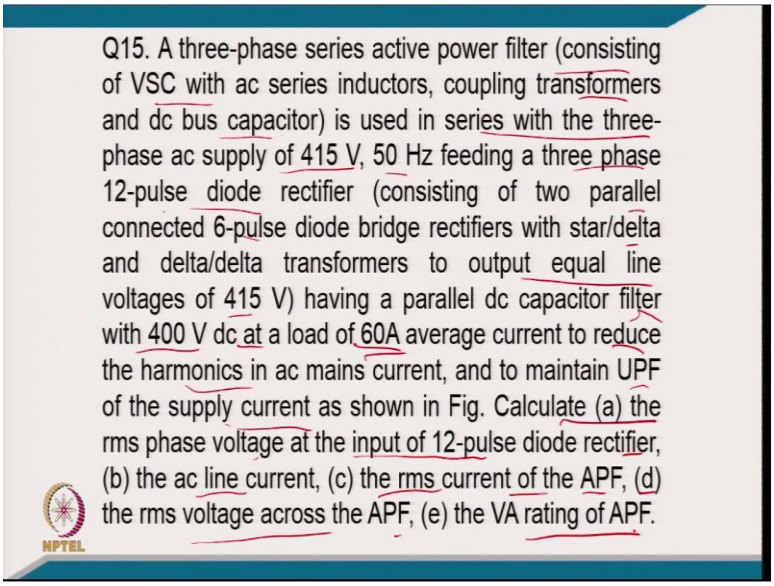

Coming to the numerical problem 15, a three-phase series active power filter consisting of voltage source converter with the ac series inductor, coupling transformer and dc bus capacitor is used to in series with the three-phase ac supply of 415 volt, 50 hertz feeding a three-phase 12 pulse diode rectifier consisting two parallel connected 6 pulse diode bridge rectifier with the star delta.

And star and delta, delta transformer to output equal to the line voltage of 415 volt having the parallel dc capacitors filter with 500 volt; 400 volt dc at the at a load of 60 volt average current sorry 60 ampere average current to reduce the harmonics in the ac mains current and to maintain the unity power factor of supply current as shown in the figure. Calculate a, the rms phase voltage at the input of 12 pulse diode rectifier b, the ac line current c, the rms current of the active series filter and d, the rms voltage across the active power filter, the VA rating of active power filter.

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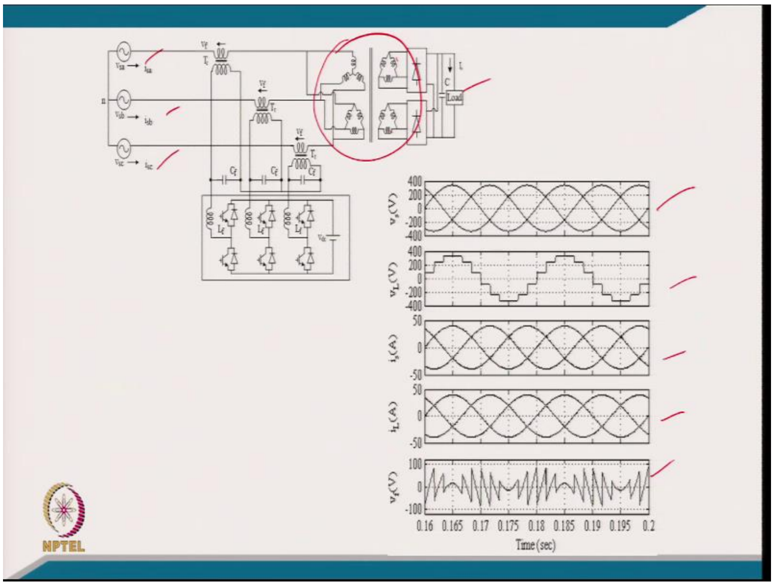

The explanation of the numerical problem is described in the screenshots herein.

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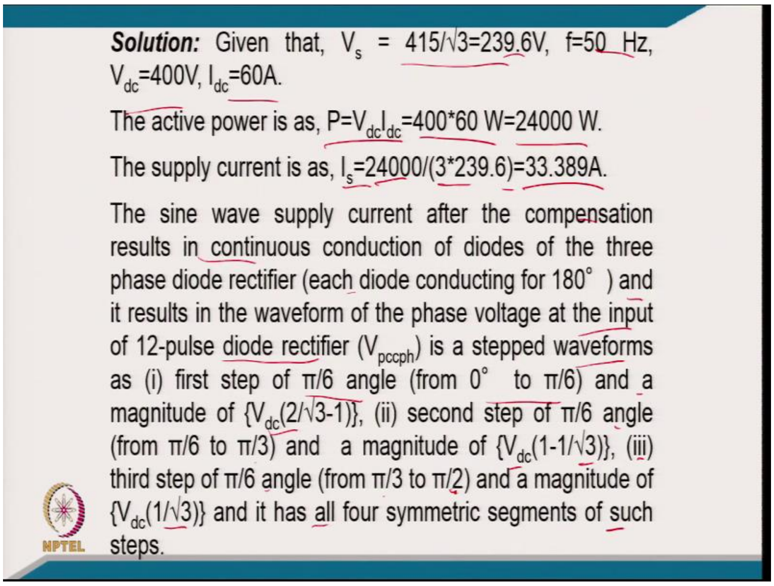

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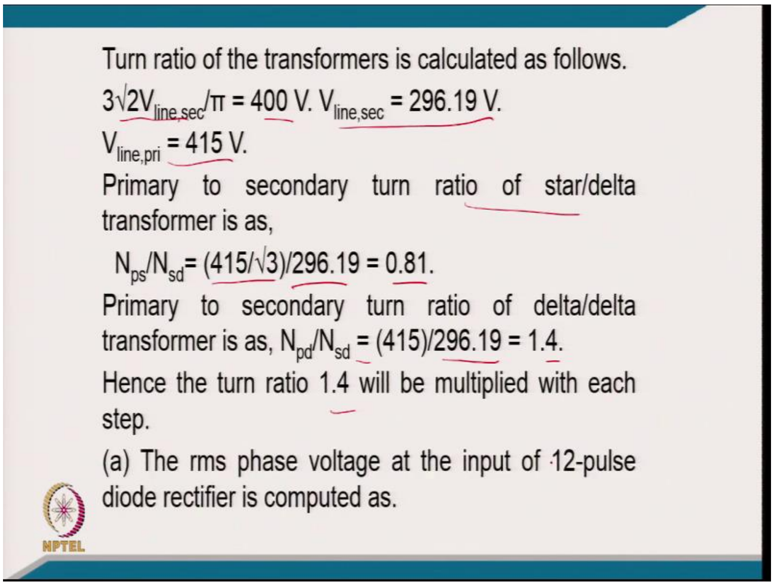

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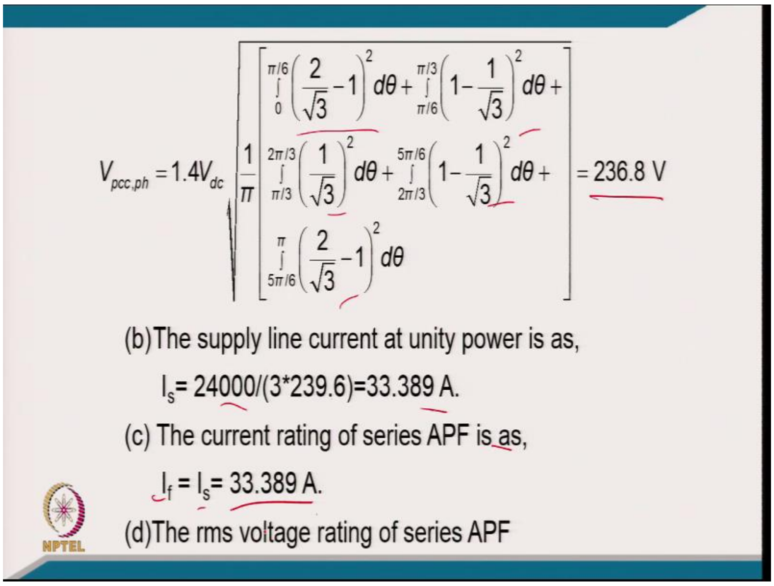

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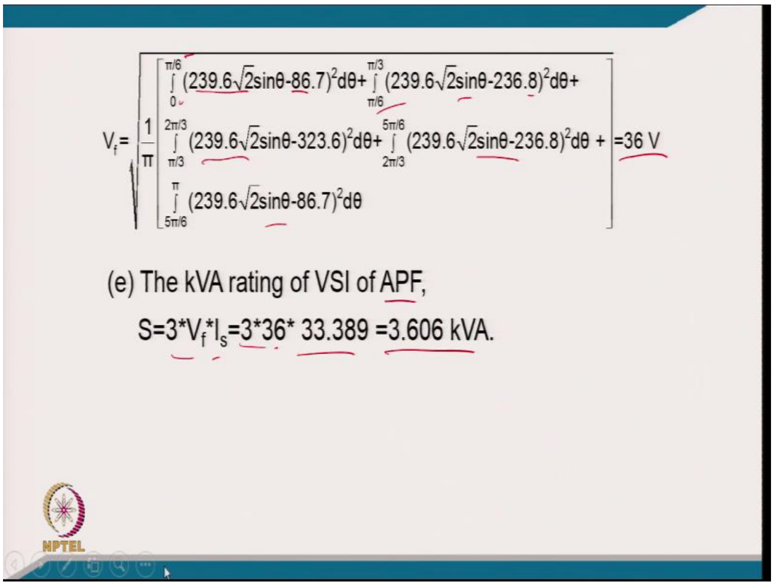

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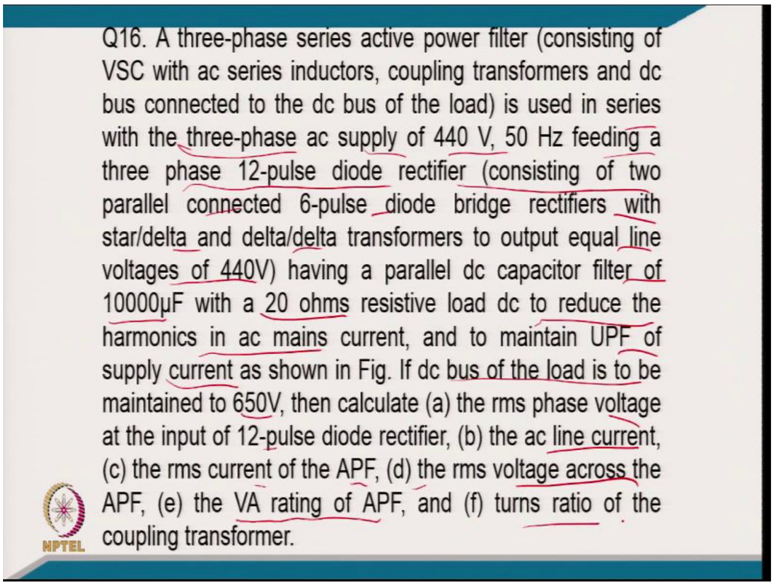

Coming to the 16 numerical problem, a three-phase series active power filter consisting of voltage source converter with the ac series inductor, coupling transformer.

And dc bus connected to the dc link of the load is used in series with the three-phase ac supply of 440 volt 50 hertz feeding a three-phase 12 pulse diode rectifier consisting of two parallel connected 6 pulse diode bridge rectifier with the star delta and delta delta transformer to the output to output equal to the line voltage of 440 volt having a parallel dc capacitor of 10000 microfarad with the 20 ohm resistive load dc to reduce the harmonics in the ac mains current and to maintain the unity power factor of the supply current as shown in the figure.

If dc bus volt; dc bus of the load is to be regulated to 650 volt, then calculate the rms phase voltage of 12 pulse diode rectifier, the ac line current and c, the rms current rating of the series active filter d, the rms voltage rating of the series active filter and e, the VA rating of series active filter and f, the turns ratio of the coupling transformer.

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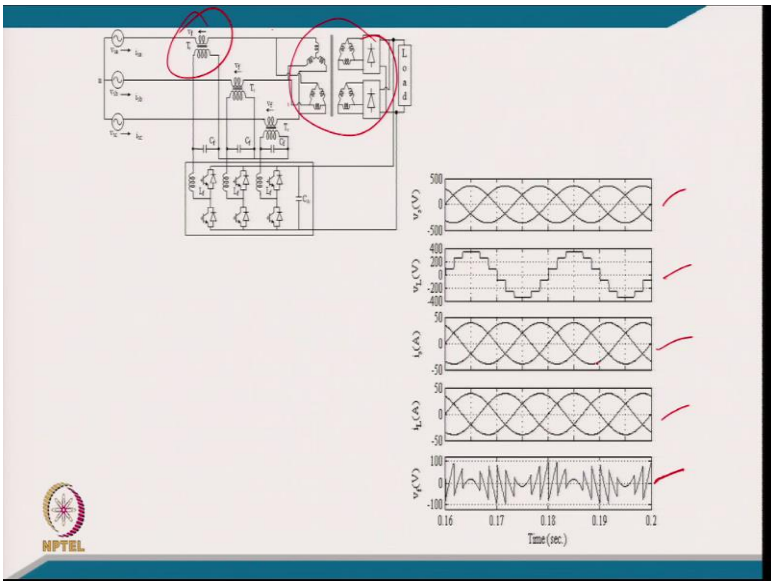

The explanation of the numerical problem is described in the screenshots herein.

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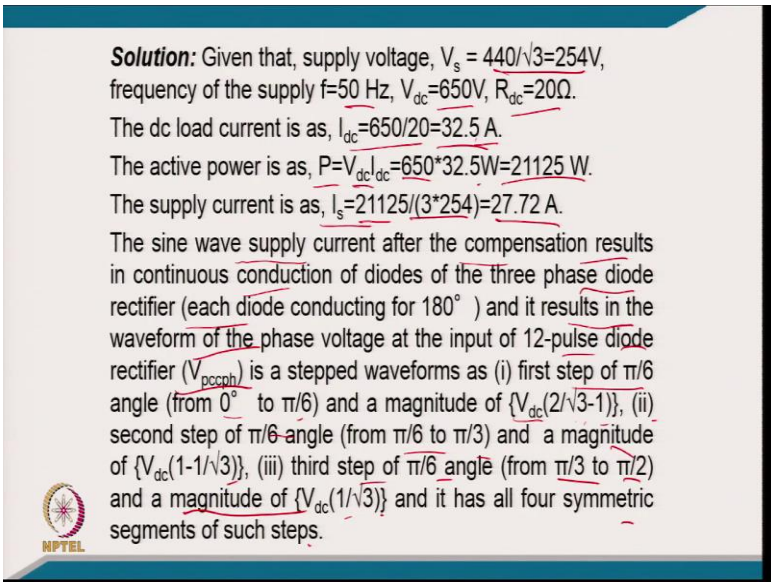

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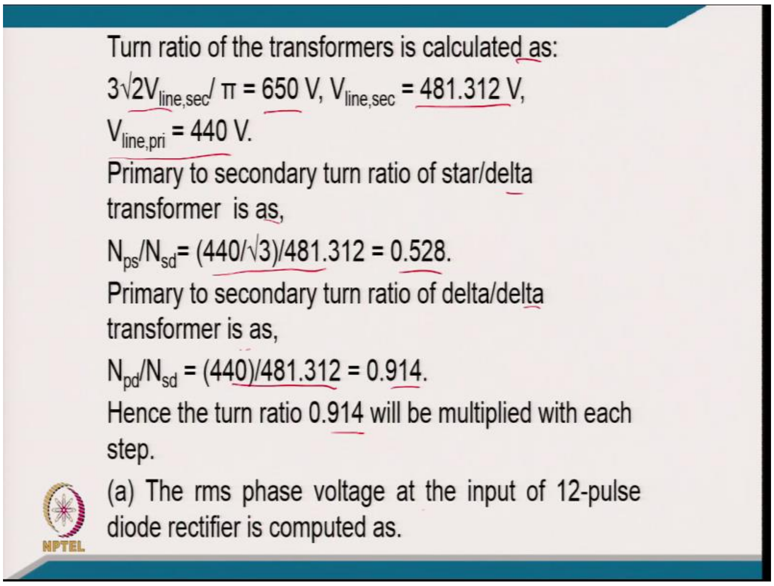

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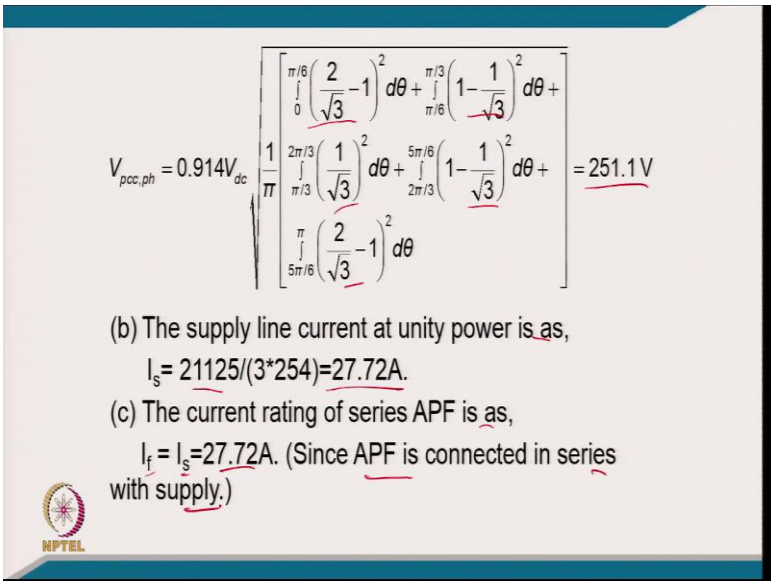

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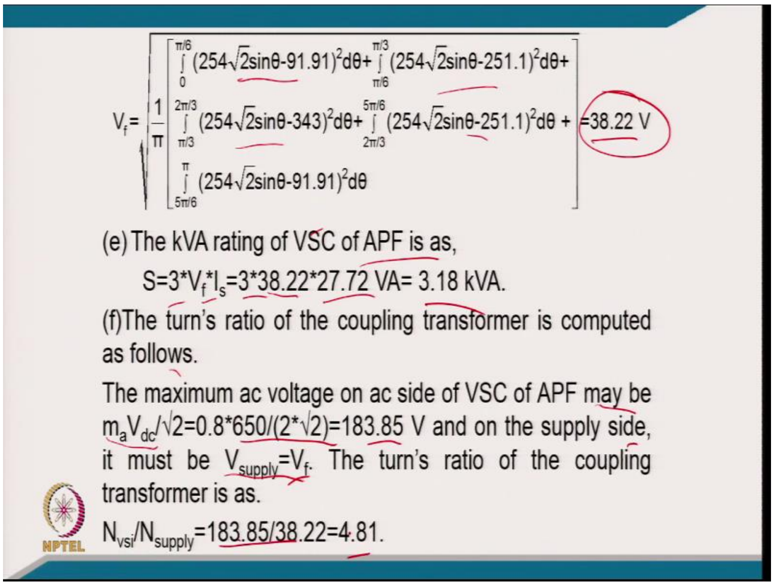

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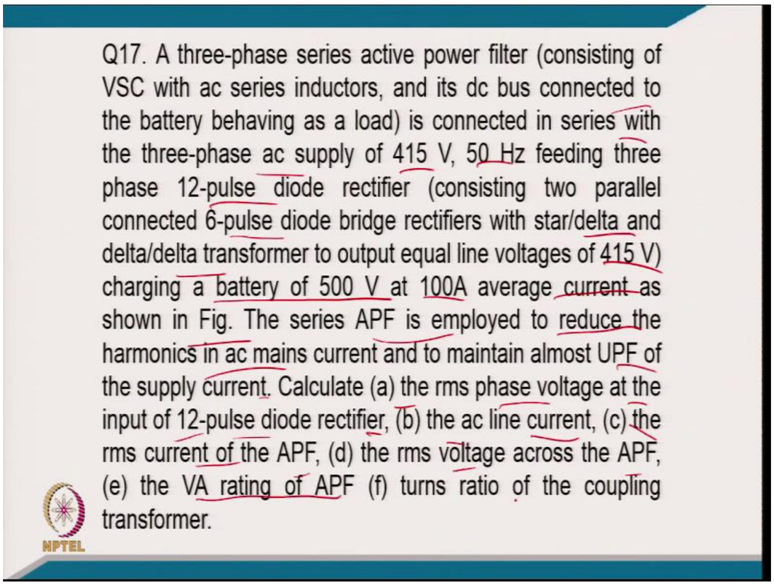

Coming to the numerical problem 17, a three-phase series active power filter consisting of voltage source converter with ac series inductor and its dc bus connected to the battery behaving as a load is connected in series with the three-phase ac supply of 415 volt, 50 hertz feeding a three-phase 12 pulse diode rectifier consisting of two parallel connected 6 pulse diode rectifier with star delta and its delta delta transformer to output equal line voltage of 415 volt charging a battery of 500 volt at a 100 ampere average current dc current as is shown in the figure.

Series active filter is employed to reduce the harmonics in ac mains current and to maintain the almost unity power factor of the supply current. Calculate a, the rms phase voltage at the input of 12 pulse diode rectifier b, the ac line current c, the ac the rms current of a series active filter the d, rms voltage across the active filter e, the VA rating of the active series active filter f, the turns ratio of the coupling transformer.

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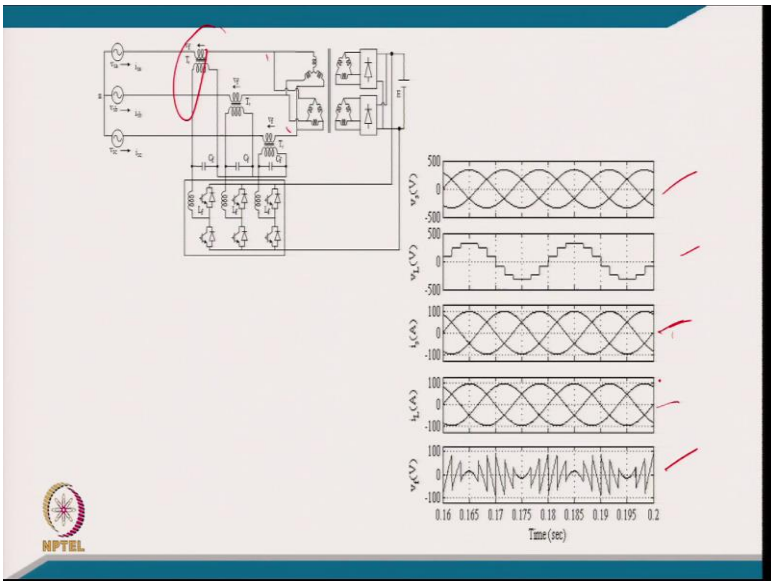

The explanation of the numerical problem is described in the screenshots herein.

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Solution: Given that, supply voltage, $V_s = 415/\sqrt{3}=239.6V$, frequency of the supply f=50 Hz, $V_{dc}=500V$, $I_{dc}=100A$.

The active power is as, $P=V_{dc}I_{dc}=500*100\ W=50000\ W$.

The supply current is as, $I_s=50000/(3*239.6)=69.56A$

The sine wave supply current after the compensation results in continuous conduction of diodes of the three phase diode rectifier (each diode conducting for 180°) and it results in the waveform of the phase voltage at the input of 12-pulse diode rectifier (V_{pccph}) is a stepped waveforms as (i) first step of π/6 angle (from 0° to π/6) and a magnitude of $\{V_{dc}(2/\sqrt{3}-1)\}$, (ii) second step of π/6 angle (from π/6 to π/3) and a magnitude of $\{V_{dc}(1-1/\sqrt{3})\}$, (iii) third step of π/6 angle (from π/3 to π/2) and a magnitude of $\{V_{dc}(1/\sqrt{3})\}$ and it has all four symmetric segments of such steps.

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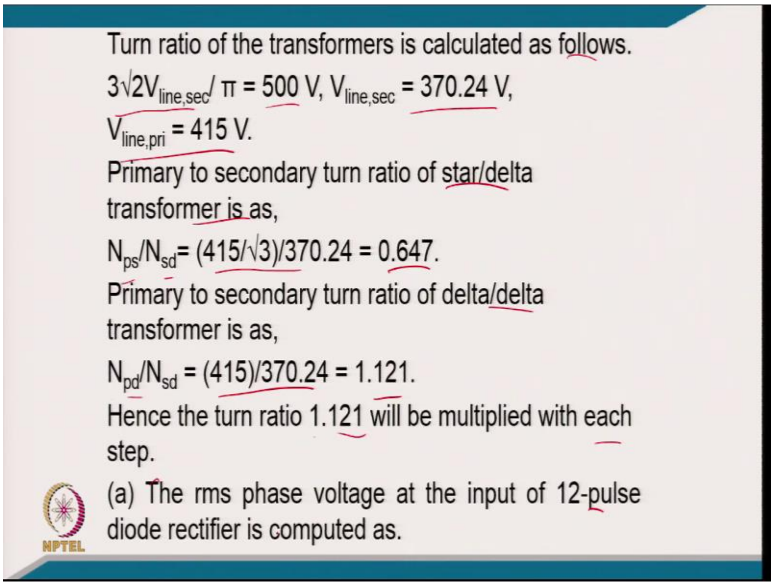

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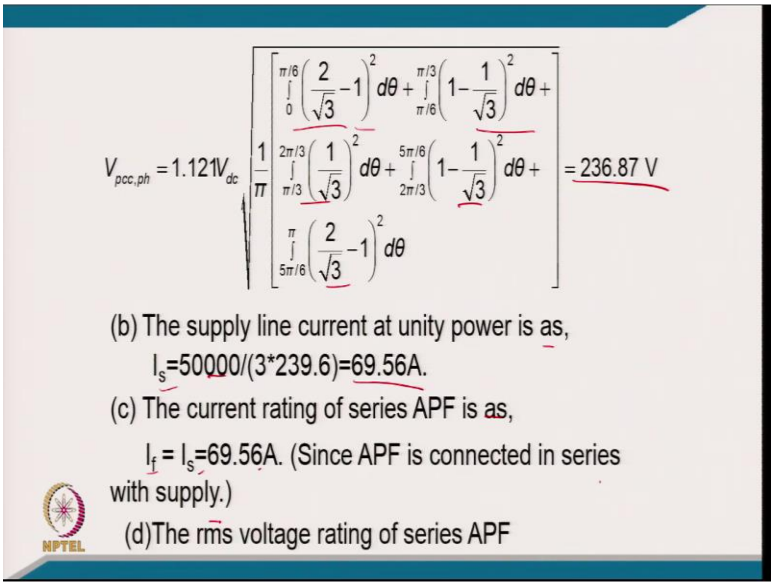

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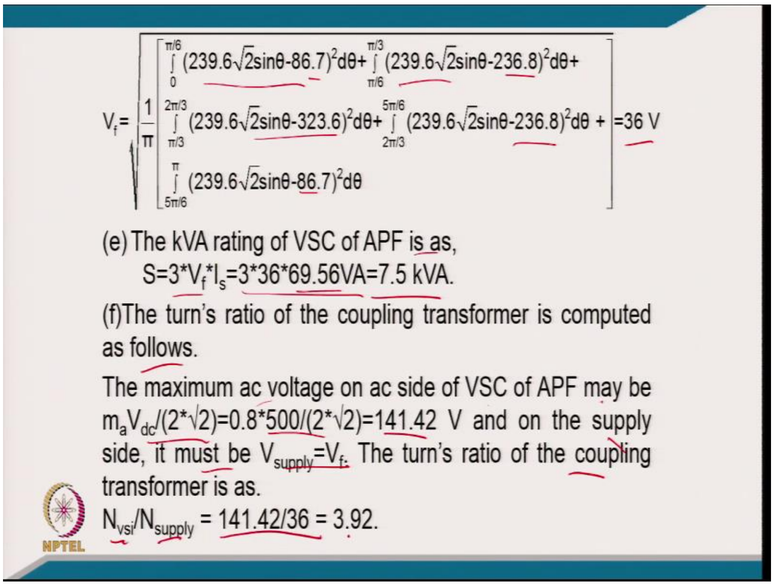

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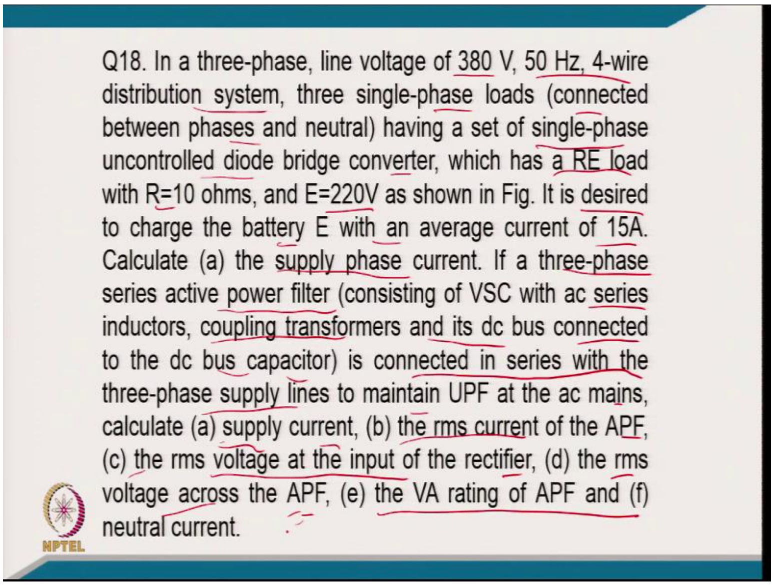

Coming to the problem number 18. In a three-phase line voltage of 380-volt, 50 hertz, 4 wire distribution system, three single phase loads connected between phase and neutral having a set of single-phase uncontrolled diode bridge converter which have a RE load of R equal to 10 ohm and E equal to 220 volt as shown in the figure. It is desired to charge the battery E with the average current of 15 ampere.

Calculate the supply phase current if three-phase series active filter consisting of VSC with series active inductor coupling transformer and dc bus connected dc bus capacitor is connected in series with the three-phase supply lines to maintain unity power factor at ac main. Calculate the a, supply current b, rms current of the act series active filter c, the rms voltage of the input of rectifier and d, the rms voltage of the voltage across the series active filter and e, the VA rating of the series again d, the neutral current.

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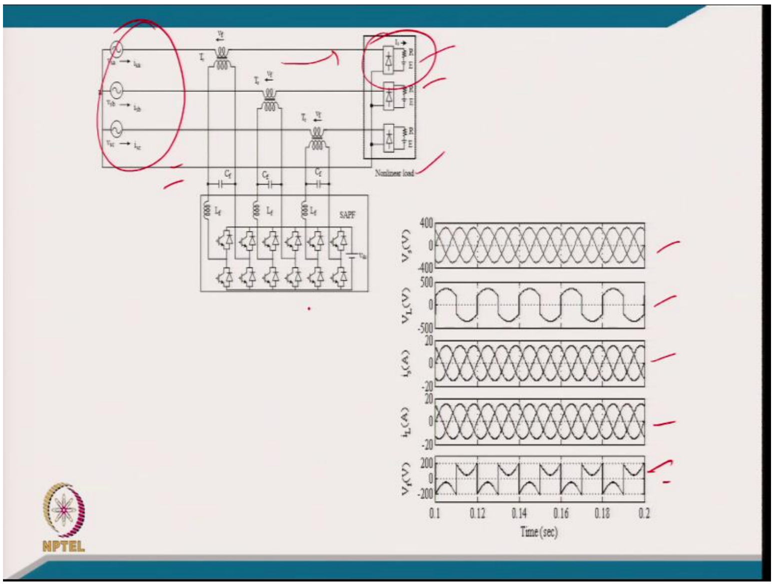

The explanation of the numerical problem is described in the screenshots herein.

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Solution: Given that, V_s=380/√3=219.39V, f=50 Hz, a load of R=10Ω, E=220V and I_{dc}=15A.

Since a series active filter is used to make the supply current sinusoidal. The rms supply current corresponding to average current of I_{dc} is as,

$I_s=\pi I_{dc}/(2*\sqrt{2})=16.661A$.

The active power is as,

$P= 3(I_s^2R+E\ I_{dc}) = 3(16.661^2*10+15*220) =3*6075.83$

P =18227.479 W.

The supply current is as, I_s=16.661A.

(a) The supply line current at unity power is as,

I_s=16.661A.

(b) The current rating of series APF is as,

$I_f = I_s$=16.661A.

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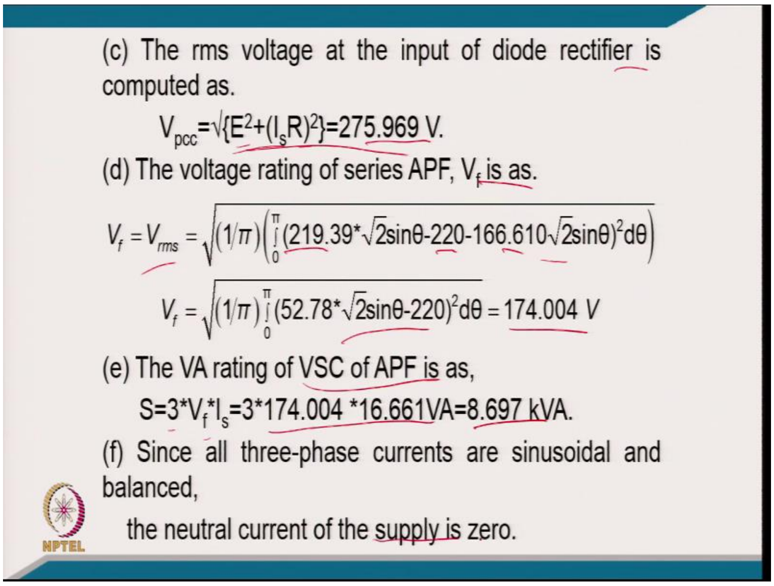

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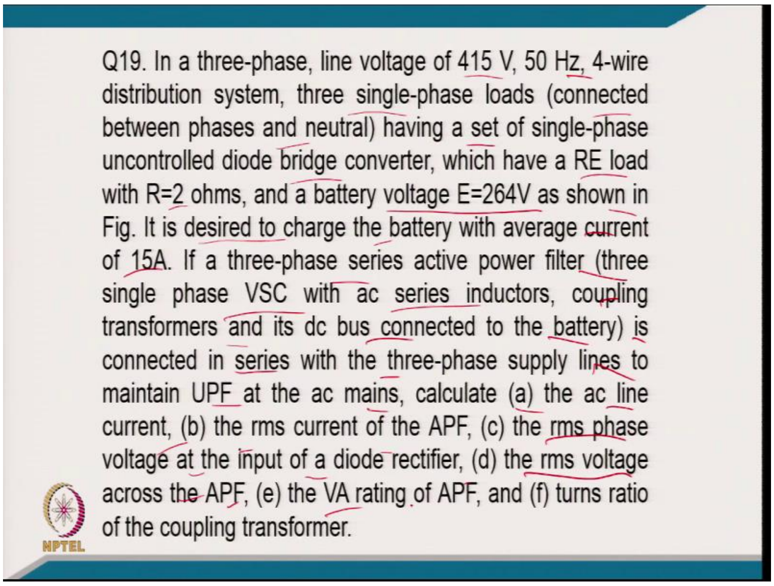

Coming to the 19 problem, in a three-phase line voltage of 415 volt, 50 hertz, 4-wire distribution system, three single-phase load connected between the phase and neutral having a set of single phase uncontrolled diode bridge converter which have a RE load equal to R equal to 2 ohm and battery voltage 264 as shown in the figure.

It is desired to charge the battery with the average current of 15 ampere. If the three-phase series active power filter single phase voltage source converter with the ac series inductor, coupling transformer and dc bus is connected to the battery is connected in series with the three-phase supply line to maintain the unity power factor at ac mains. Calculate a, ac line current b, the rms current of the APF c, the rms phase voltage at the input of diode rectifier d, the rms voltage across the APF and the VA rating of APF and f is the turns ratio of coupling transformer.

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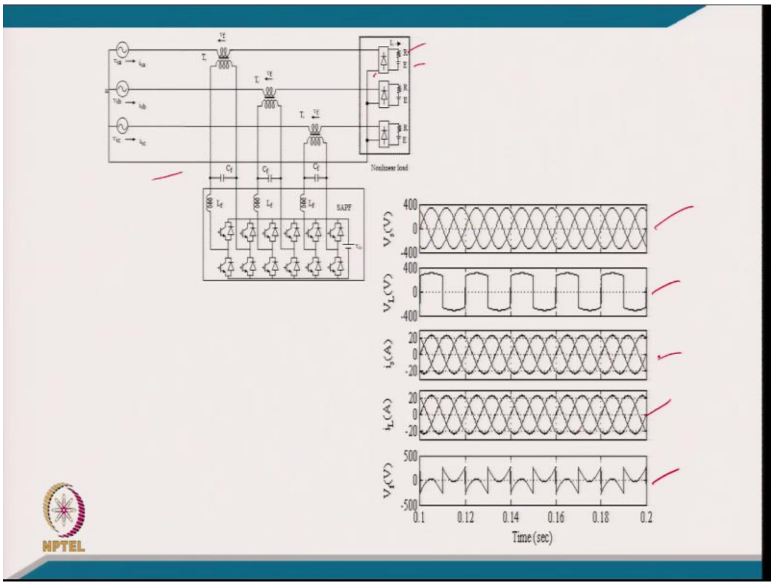

The explanation of the numerical problem is described in the screenshots herein.

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Solution: Given that, supply phase voltage, $V_s=415/\sqrt{3}=239.6V$, frequency of the supply, f=50 Hz, a load of $R=2\Omega$, E=264V and $I_{dc}=15A$.

Since a series active filter is used to make the supply current sinusoidal in each phase. The rms supply current corresponding to average current of I_{dc} is as, $I_s=\pi I_{dc}/(2*\sqrt{2})=16.66A$.

The active power is as, $P= 3(I_s^2R+E\ I_{dc})$

$P= 3(16.66^2*2+15*264)= 3*4515 = 13545W$.

(a) The rms supply line current at unity power is as,

$I_s=16.66A$.

(b) The rms current rating of series APF is as,

$I_f=I_s=16.66A$.

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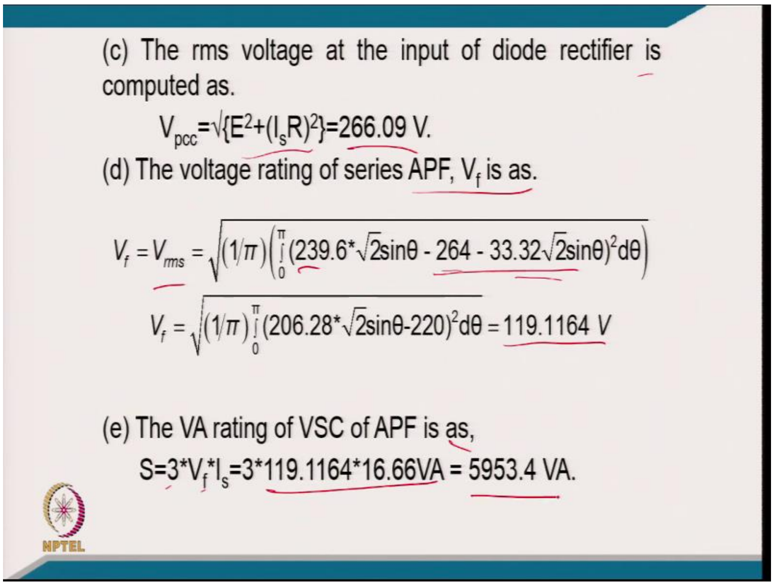

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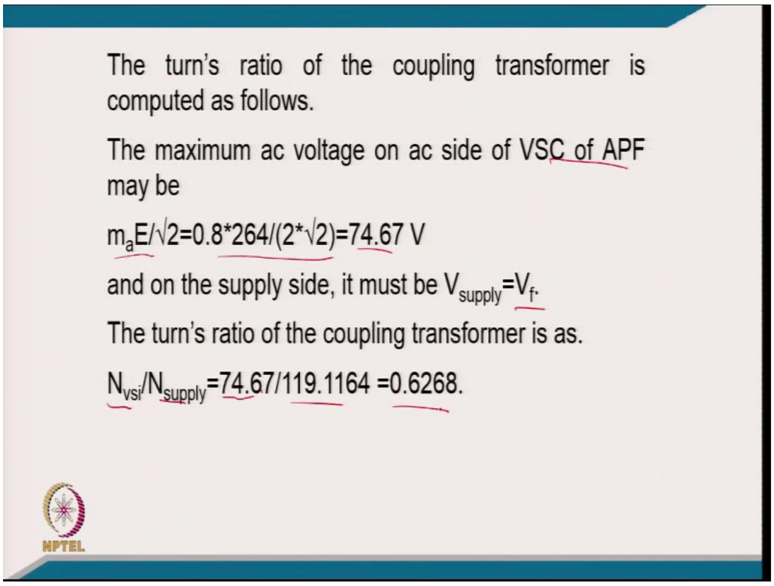

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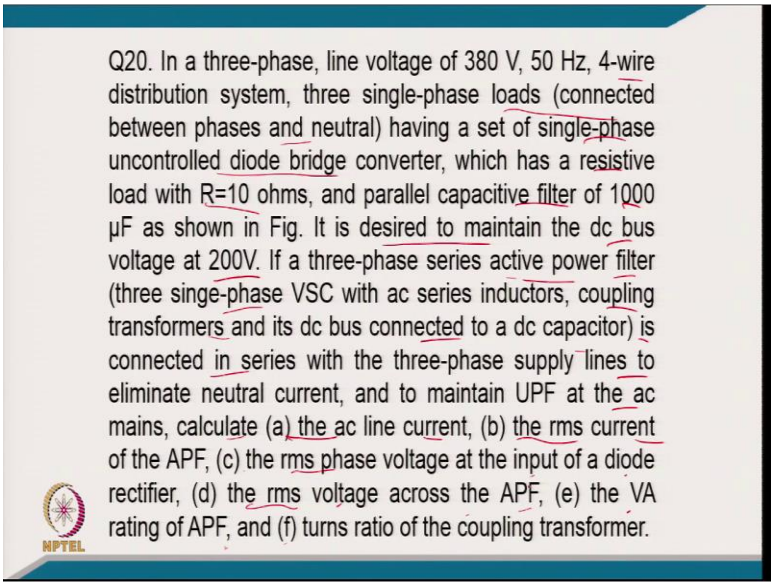

Coming to the solved example of 20. In the three-phase line voltage of 380 volt, 50 hertz, 4-wire distribution system, three single-phase load connected between phase and neutral having a set of single phase uncontrolled diode bridge converter which has a resistive load R to 10 ohm and parallel capacitive filter of 1000 micro farad it is desired to maintain dc bus voltage of 200 volt.

If the three-phase series active filter three single phase VSC with the ac series inductor, coupling transformer and its dc bus connected to a capacitor is connected in series with the three-phase supply line to eliminate neutral current and to maintain unity power factor of the ac main.

Calculate a, the ac mains line current b, the rms current of the active filter c, is the rms phase voltage at the input of diode rectifier and d, the rms voltage across the active power filter and the VA rating of active filter, e and f is the turns ratio of coupling transformer.

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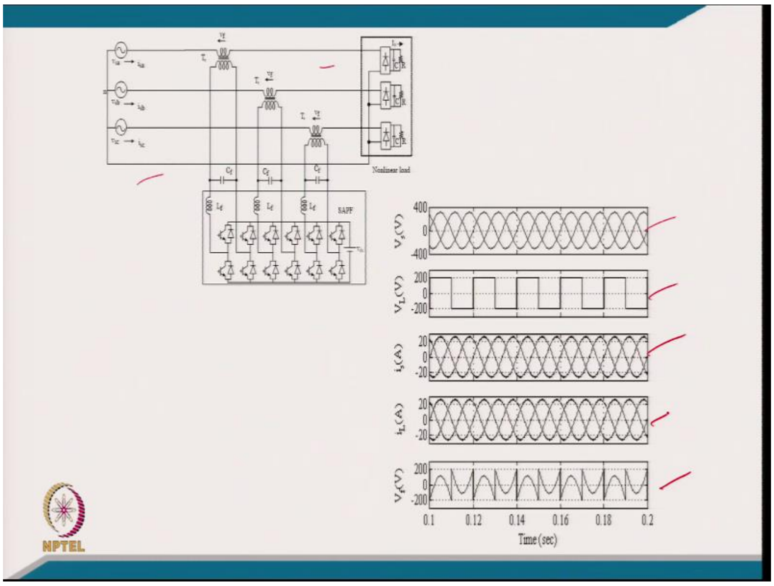

The explanation of the numerical problem is described in the screenshots herein.

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Solution: Given that, supply phase voltage, V_s=380/√3=219.39V, frequency of the supply, f=50 Hz, a load of R=10Ω, V_{dc}=200V.

The dc load current is as, I_{dc}=200/10=20A.

Since a series active filter is used to make the supply current sinusoidal in each phase. The rms supply current corresponding to it is as,

I_s=200*20/219.39=18.23A.

The active power is as, P= 3($V_{dc}I_{dc}$) = 3(200*20)

P =3*4000 =12000W.

(a) The rms supply line current at unity power is as,

I_s=18.23A.

(b) The rms current rating of series AF is as,

I_f = I_s=18.23A.

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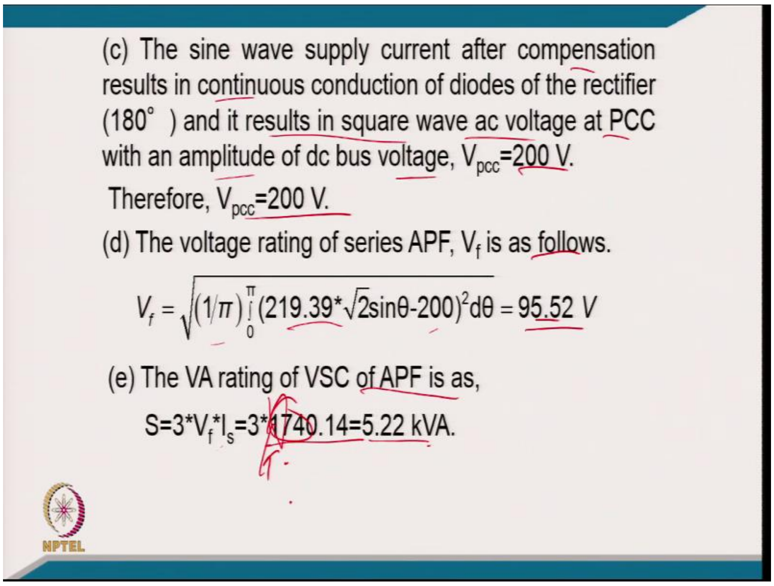

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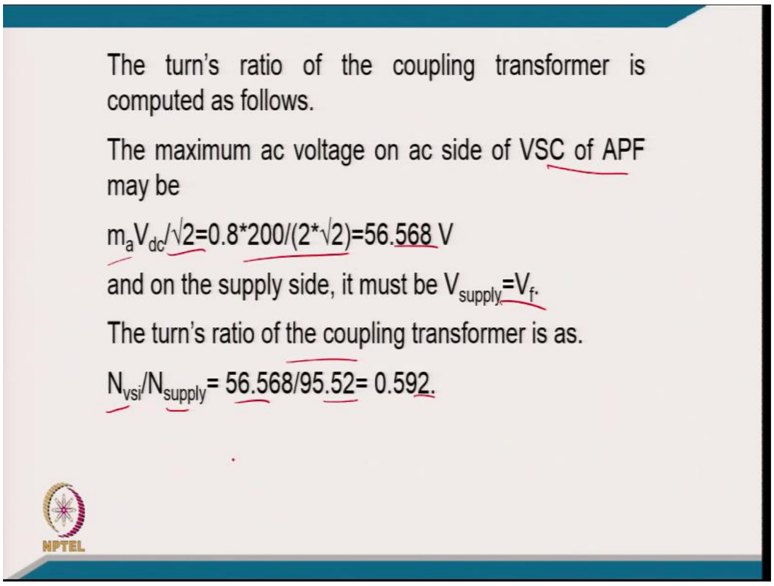

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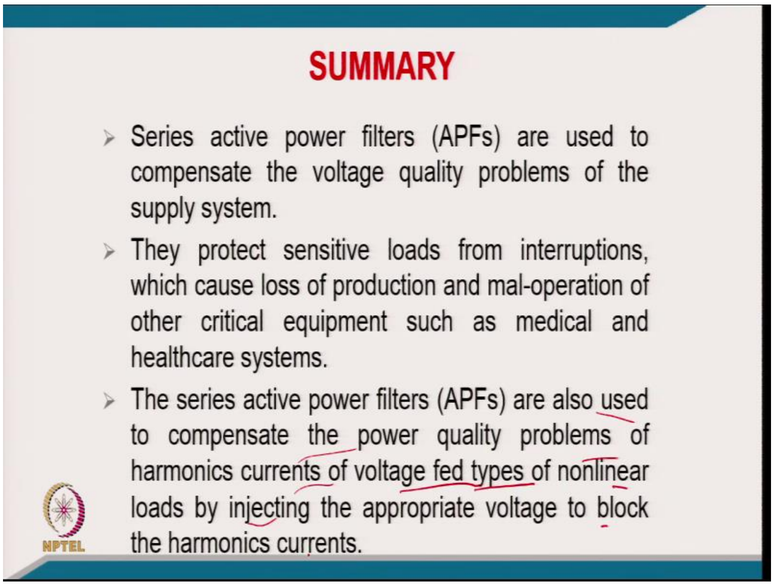

Well, we will like to summarize. Now, the series active filter are used to compensate the voltage quality problems of the supply system. They protect sensitive load from interruption which causes loss of production and mal operation of the other critical equipment such as medical and healthcare instrument, healthcare system and the series active power filter also use to compensate the power quality problems of harmonic currents of voltage fed kind of load of non-linear load by injecting the appropriate voltage to block the harmonics current like which we have given many example.

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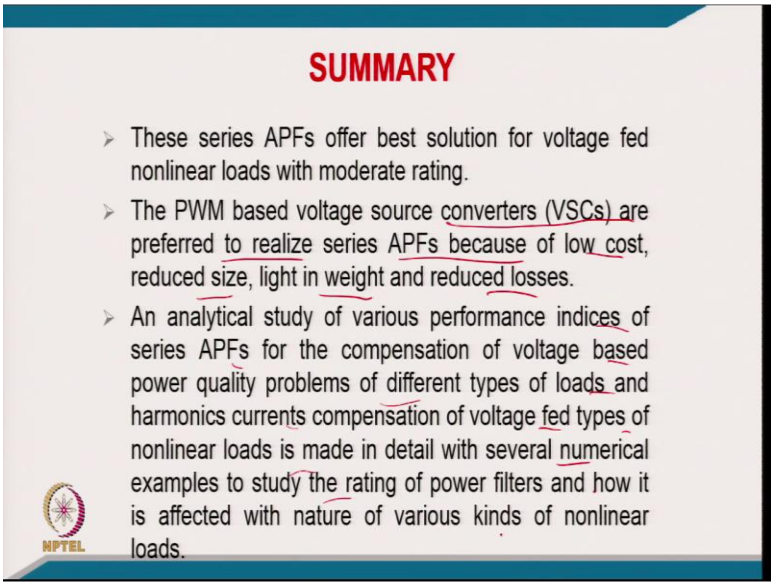

And this series active filter offered the best solution for voltage fed non-linear load with moderate rating. The PWM based voltage source inverters converters are used are preferred to realize the series active power filter because of low cost, reduce size, light in weight and reduce losses.

An analytical study of various performance indices of series active filters for compensation of voltage based power quality problem of different types of load and the harmonic current compensation of voltage fed kind of load is made in detail with the several numerical examples to study the rating of power filters and how it is affect the nature of various kind of non-linear load.

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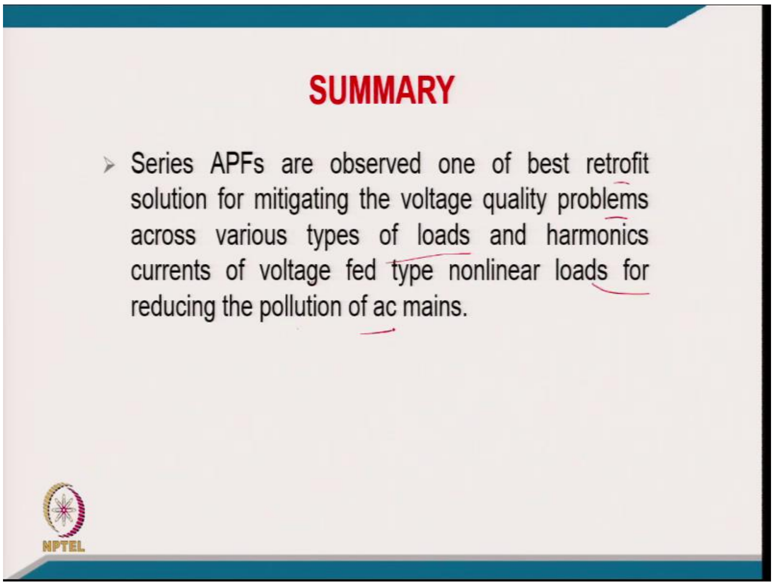

And series active filters are observed one of the best rate of it solution for mitigating voltage power quality problem across various type of load and harmonic currents of voltage fed kind of non-linear load for reducing the pollution of ac mains current.

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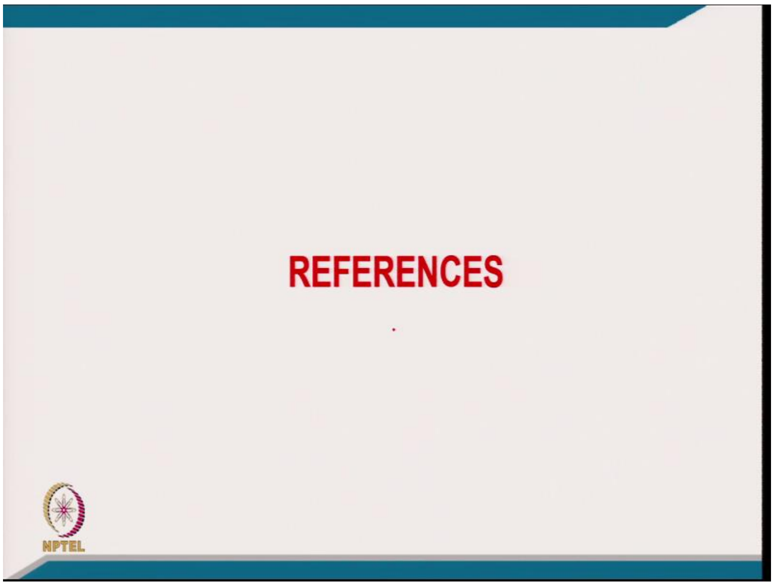

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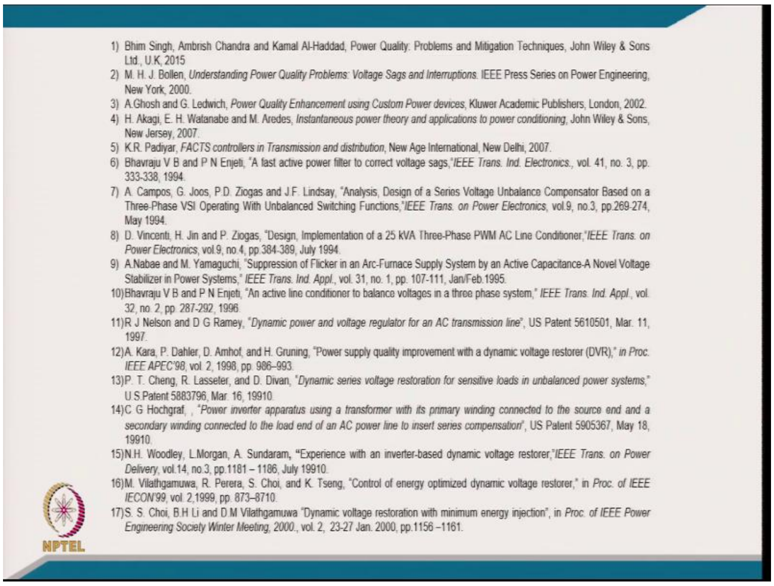

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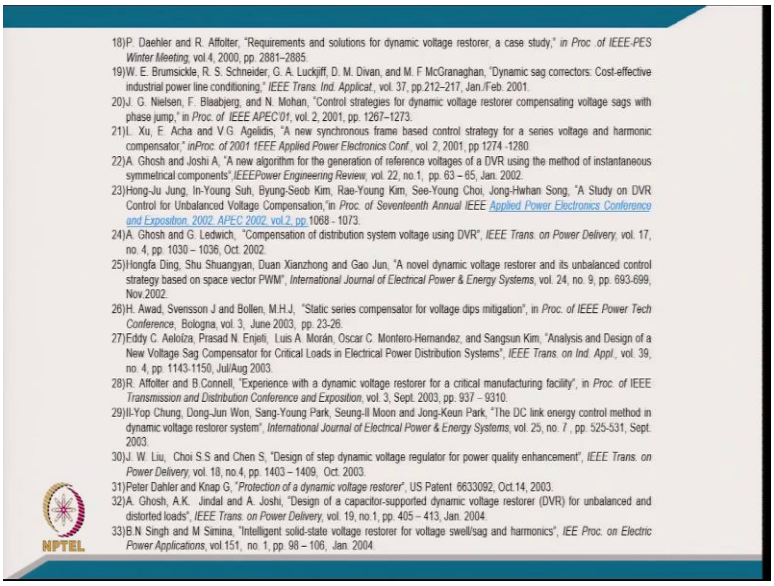

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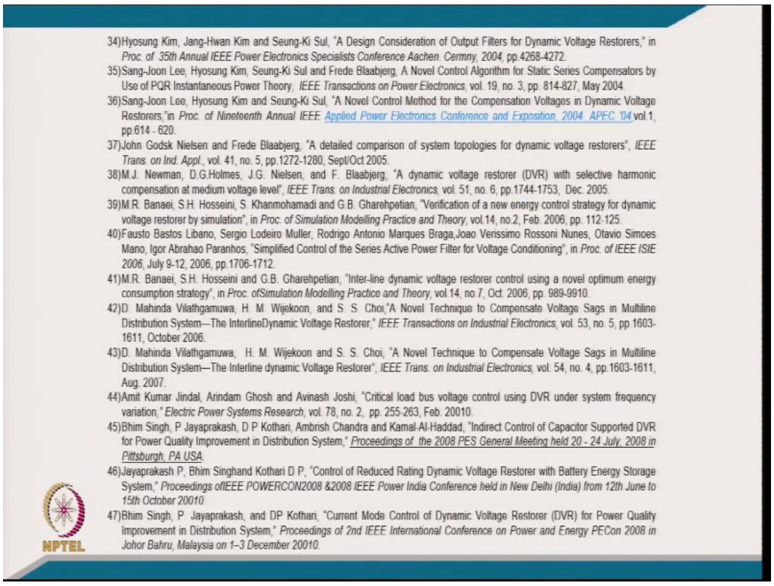

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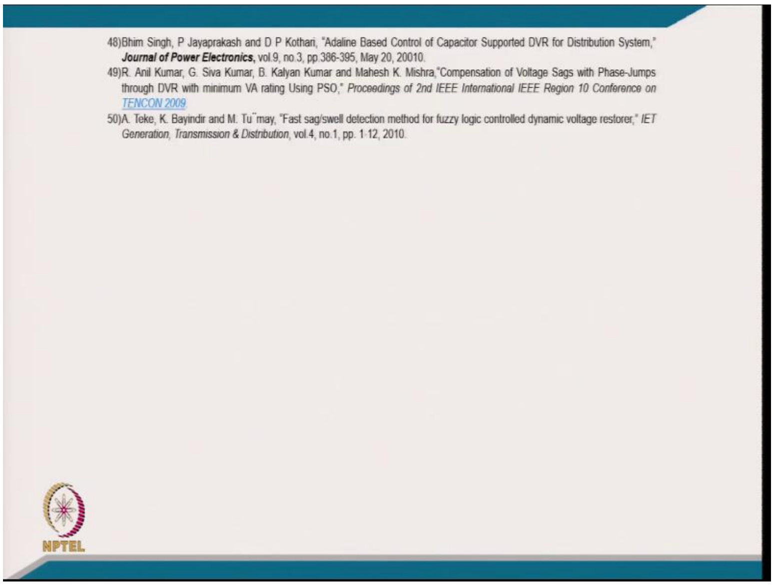

And these are the references for this topic.