Power Quality
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Chapter - 15
Module - 03
Lecture - 43
Power Quality Improvement in Diesel Generator Set Based Power Supply System

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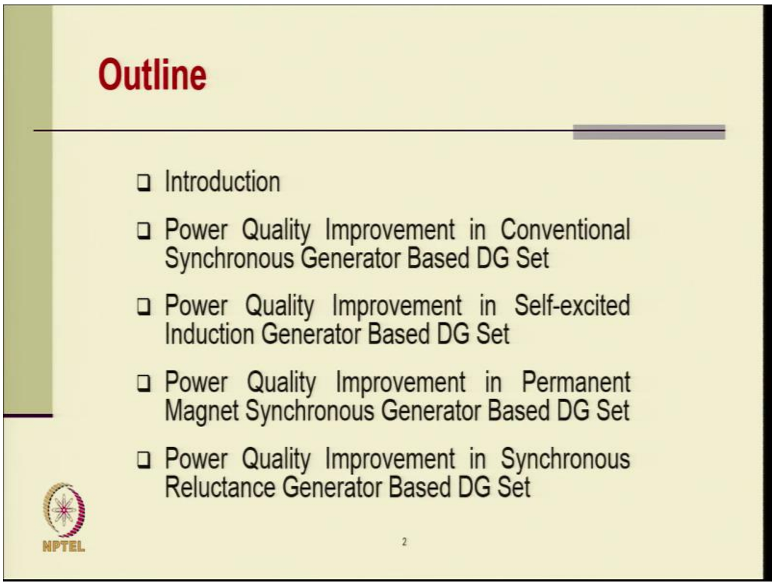

Welcome to the course on power quality. We will discuss today the Power Quality Improvement in Diesel Generator Set Based Power Supply System with the outline that will introduce the power quality improvement in conventional synchronous generator-based diesel generator set and power quality improvement in self excited induction generator based DG set. And power quality improvement in permanent synchronous generator based diesel generator set and the power quality improvement in synchronous reluctance based DG set.

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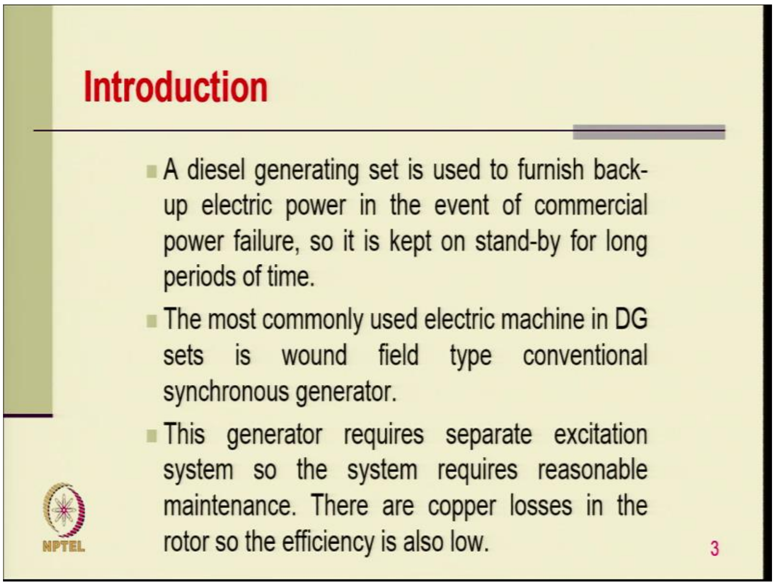

Coming to introduction. A diesel generating set is used to furnish backup electric power to the event of commercial power failure, so it is kept on stand-by for long periods of time. The most commonly used electrical machines in DG sets is wound field type conventional synchronous generator. This generator requires separate excitations. So, the system requires reasonable maintenance and there are copper losses in the rotor so the efficiency is also low.

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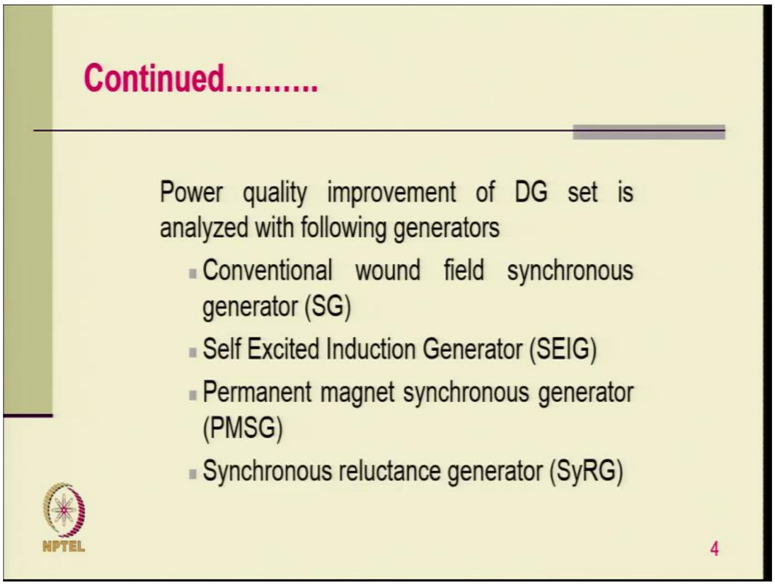

And power quality improvement of DG set is analyzed with the following generator with conventional wound field synchronous generator, with self-excited induction generator, with permanent synchronous generator, and synchronous reluctance generator.

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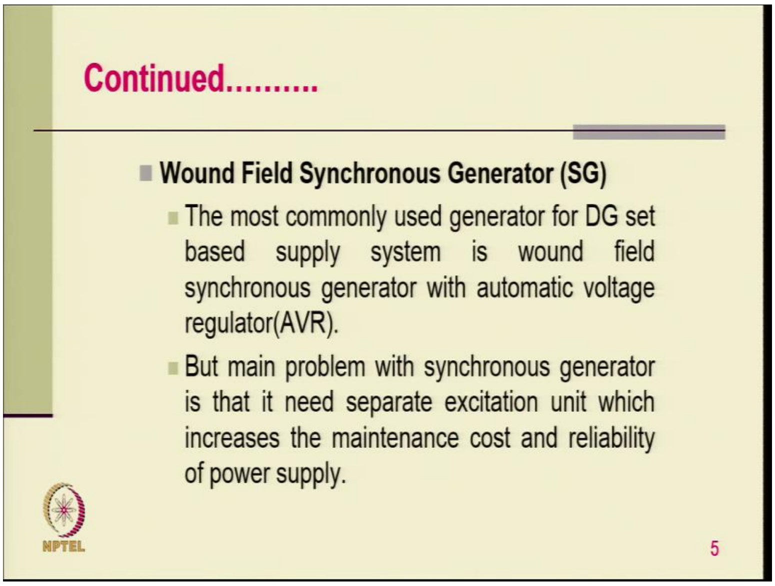

Well, coming to the wound field synchronous generator. The most commonly used generator for DG sets supply system is wound field synchronous generator with automatic voltage regulator, but the main problem is synchronous generator is that the need separate excitation unit which increases maintenance and cost and reliability of the supply.

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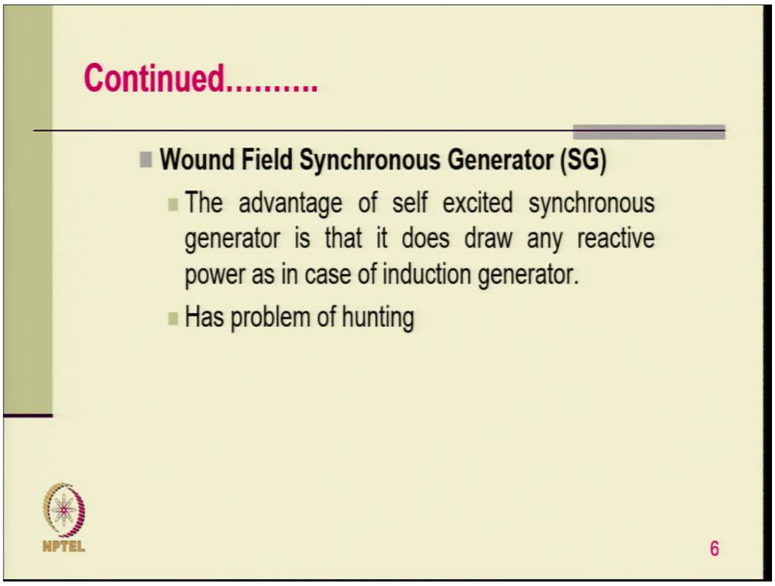

And the advantage of self excited synchronous generator is that it does not draw any reactive power in case of as in generator. It has the problem of hunting.

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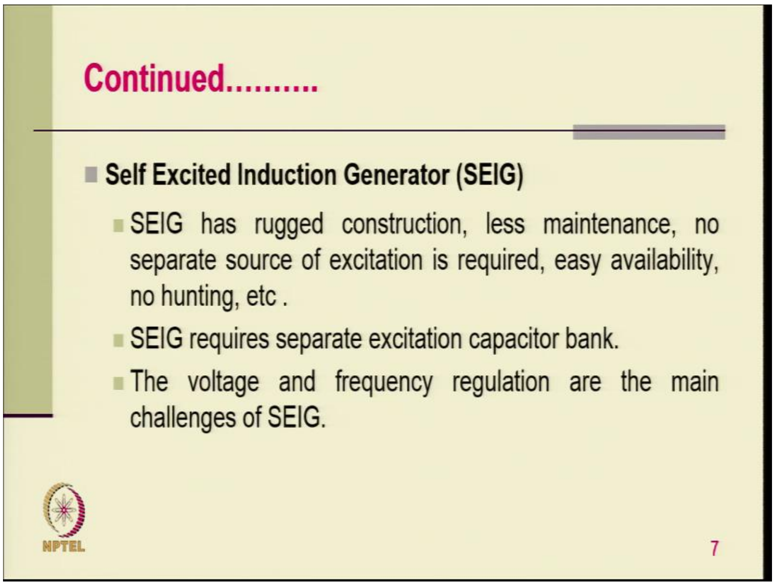

And self excited induction generator has rugged construction, less maintenance, and no separate source of excitation is required, so, easy availability, and no hunting phenomena. The Self Excited induction generator requires separate excitation capacitor bank. Voltage and frequency regulation are main challenge of the self excited induction generator.

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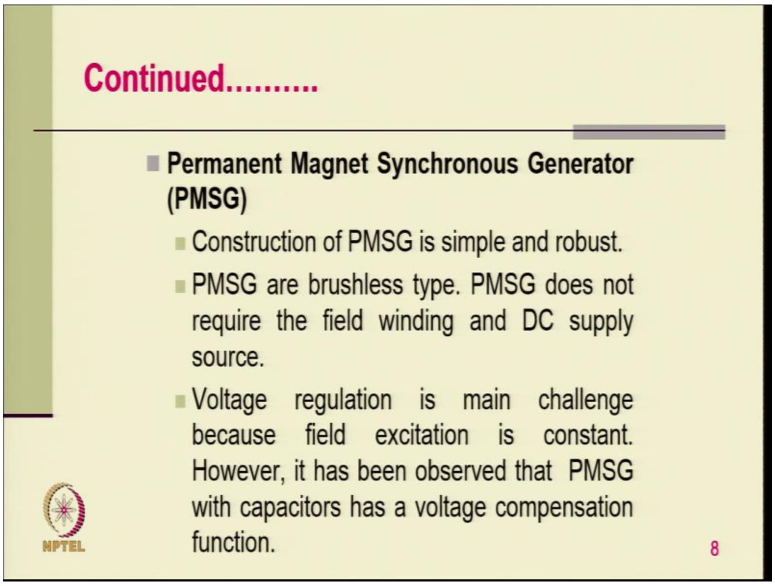

Coming to permanent magnet synchronous generator. The construction of PMSG is simple and robust. The permanent generators are brushless type and does not require the field winding and DC supply source. Voltage regulation is the main challenge, because the field excitation is constant. However, it has been observed that PMSG with capacitor has the voltage compensation function.

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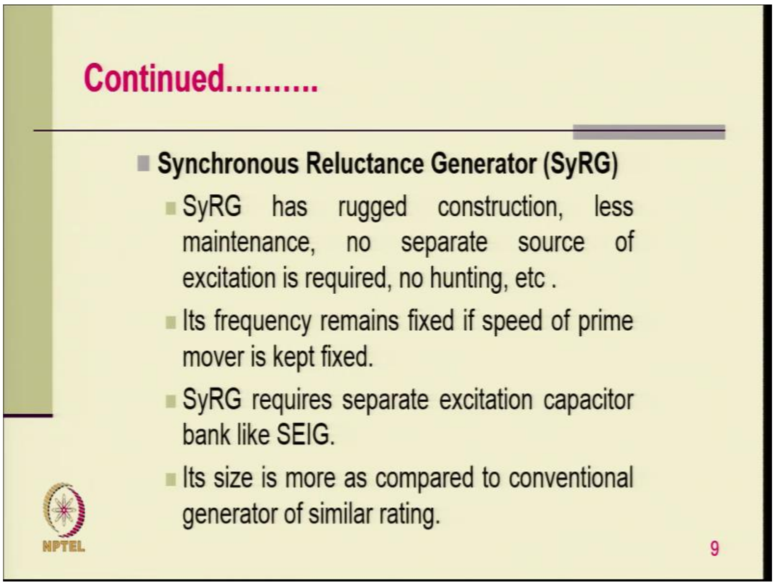

And, the synchronous reluctance generator has rugged construction, less maintenance, and no separate source for excitation is required, and its frequency remains fixed, if the speed of prime mover is fixed. The synchronous reluctance generator requires separate excitation capacitor like SEIG. Its size is more as compared to conventional generator of same rating.

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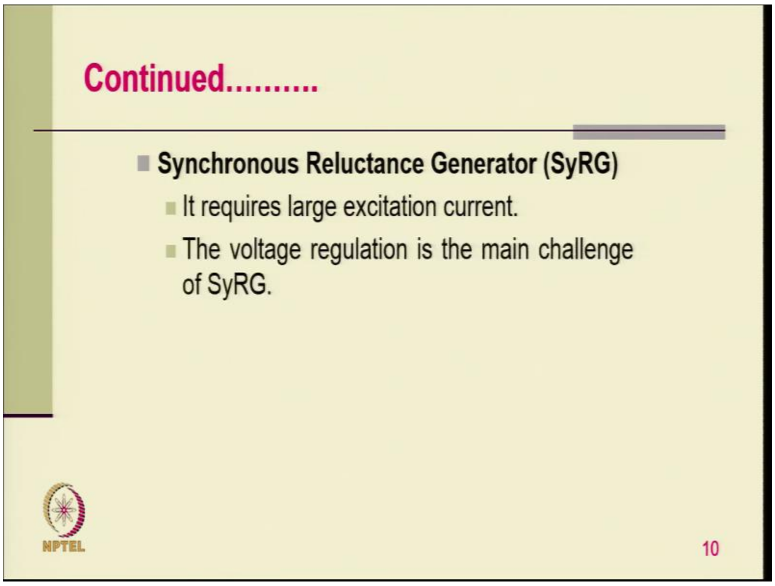

It requires large excitation current and voltage regulation is the main challenge of synchronous reluctance generator.

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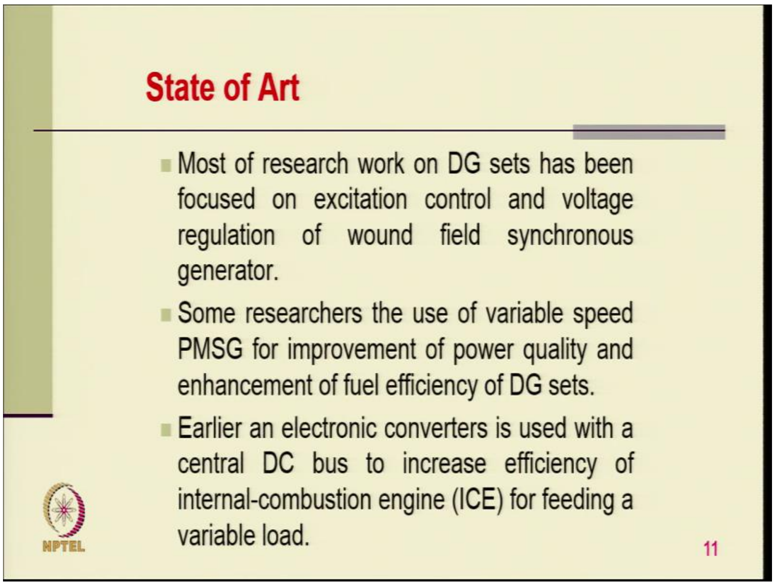

Most of the research work on DG sets have been focused on excitation control and voltage regulation of wound field synchronous generator. Some researchers have used the variable speed permanent magnet for improvement of power quality and enhancement of fuel efficiency of DG set. Earlier an electronics controller is used with central DC bus to increase efficiency of internal-combustion engine for feeding the variable load.

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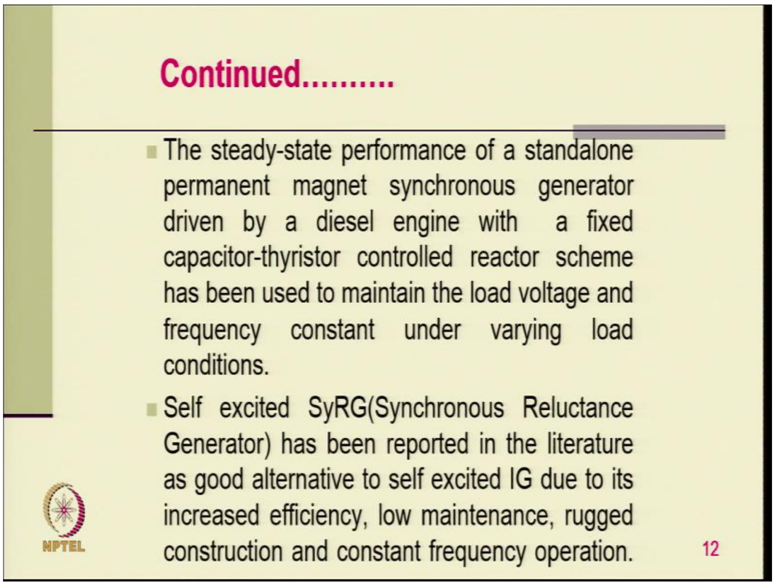

The steady-state performance of a standalone permanent magnet generator driven by diesel engine with a fixed capacitor-thyristor controlled reactor scheme has been used to maintain the load voltage and frequency constant under varying condition. The self-excited synchronous generator has been reported in the literature as good alternative to self excited induction generator, due to its increased efficiency, low maintenance and rugged construction with constant frequency operation.

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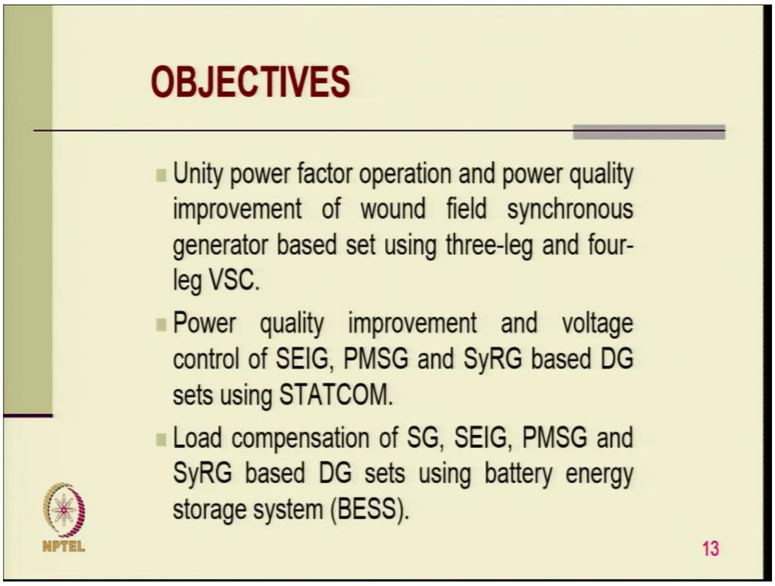

Now, coming to the objectives. The unity power factor operation and power quality improvement of wound field synchronous generator-based set using three-leg and four-leg voltage source converter. The power quality improvement and voltage control of self excited induction generator, permanent synchronous reluctance generator using static compensators. Load compensation of synchronous generator self exciting permanent generator and synchronous reluctance-based DG sets using the battery energy storage system.

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Well, this is the typical example of diesel generating set.

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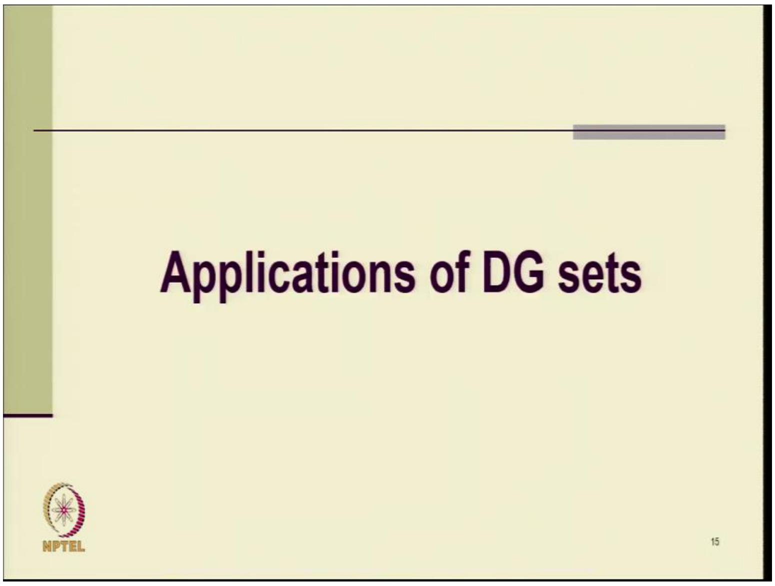

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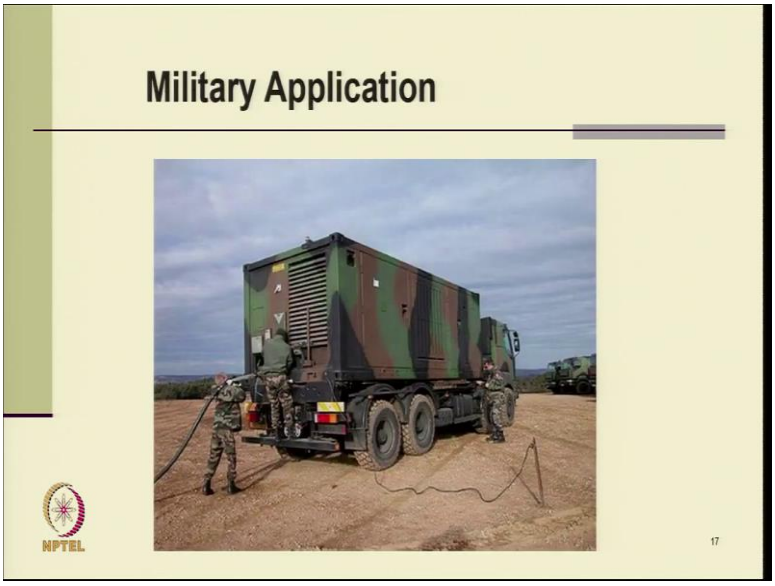

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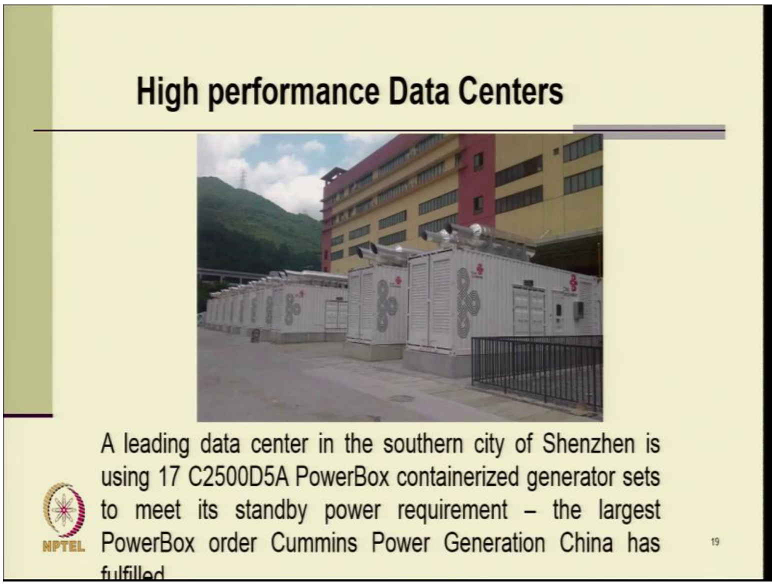

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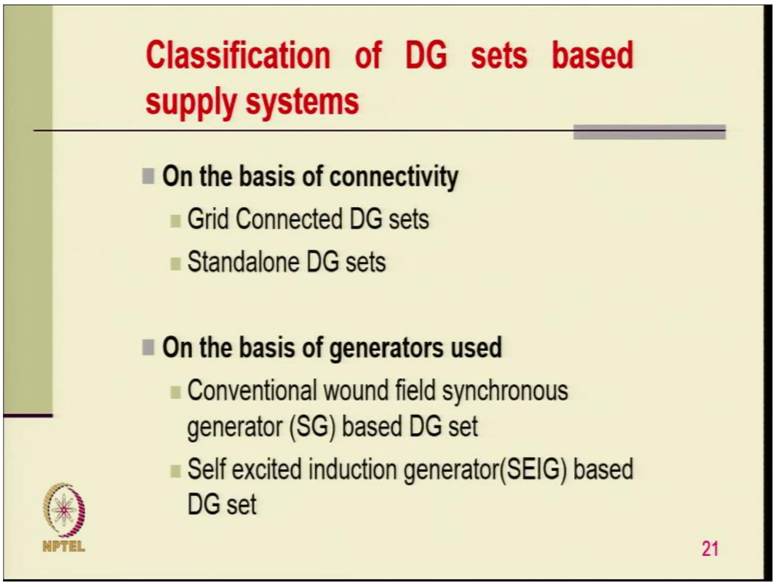

This is the classification of DG sets based supply systems.

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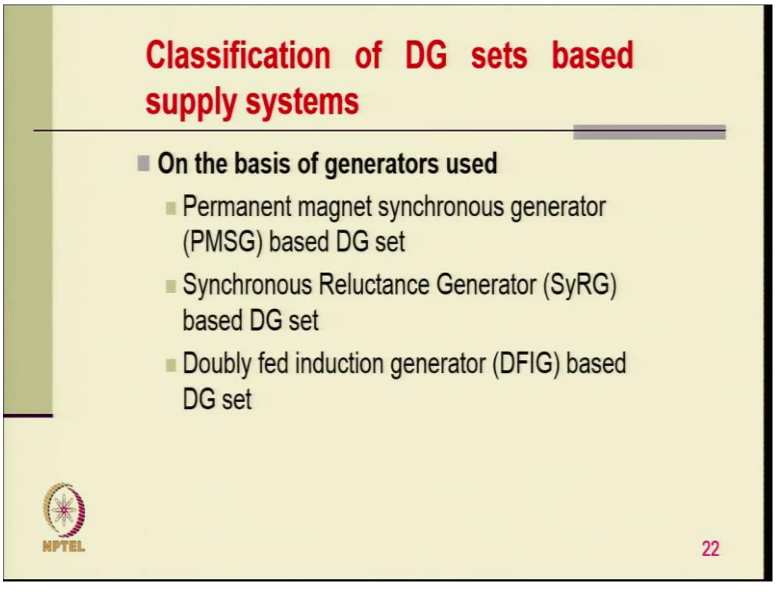

This is the classification of DG sets based supply systems.

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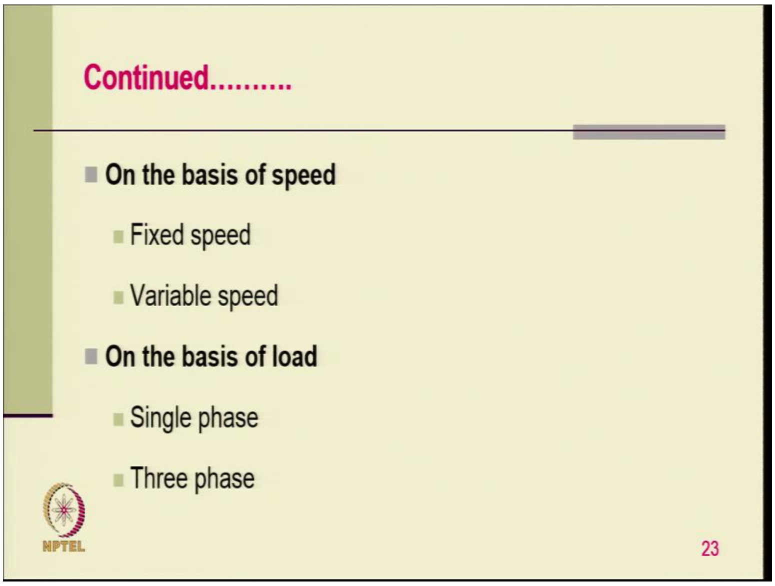

This is the classification of DG sets based supply systems.

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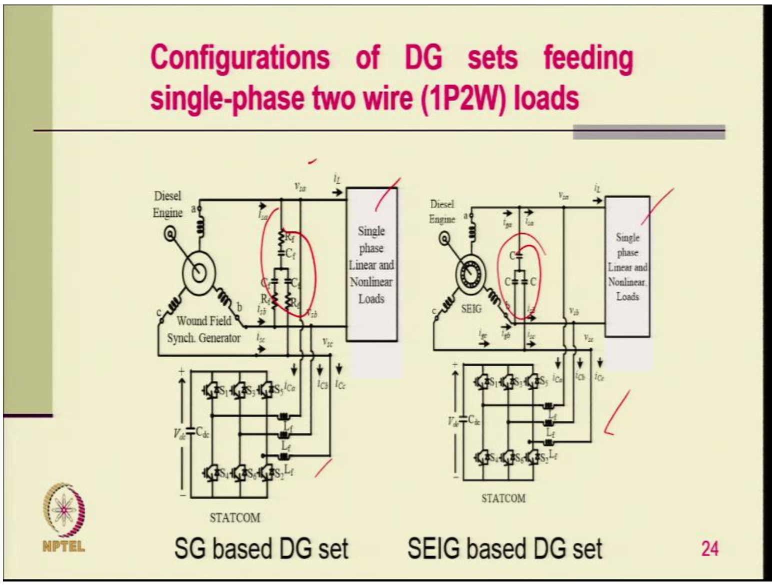

These are the configurations of SG and SEIG based DG sets feeding single phase two wire (1P2W) loads.

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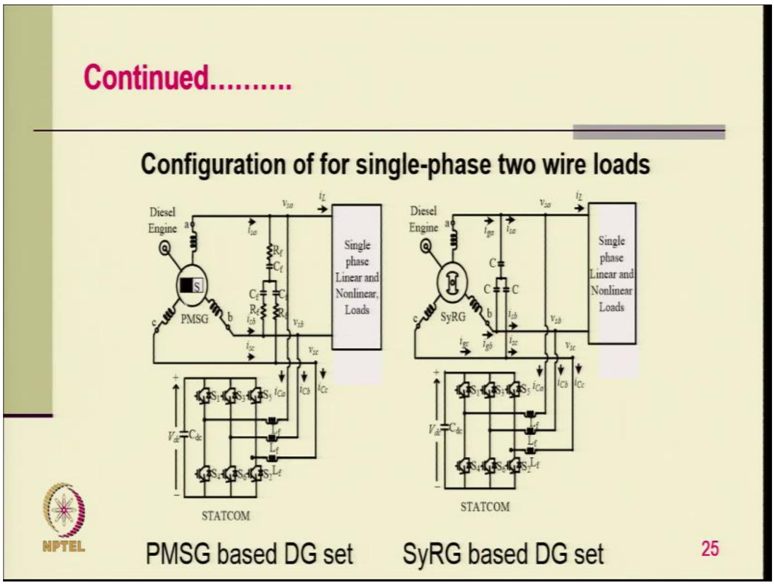

These are the configurations of PMSG and SyRG based DG sets feeding single phase two wire (1P2W) loads.

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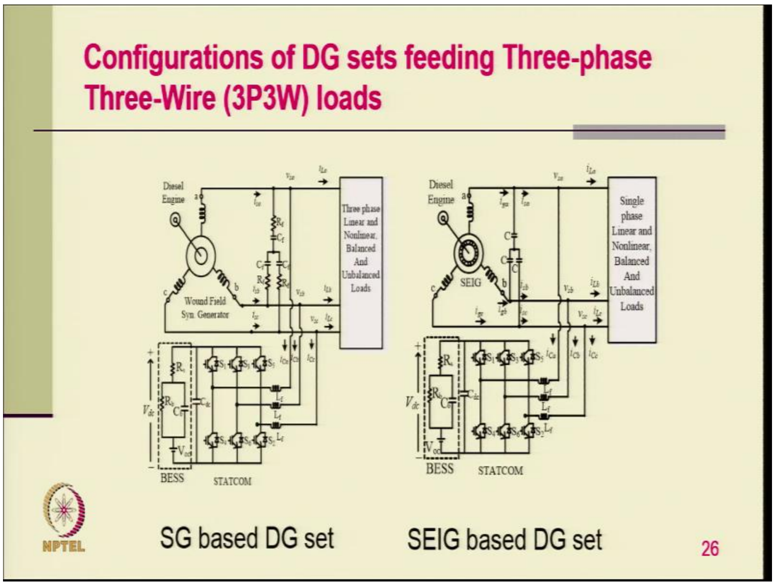

These are the configurations of SG and SEIG based DG sets feeding Three phase Three wire (3P3W) loads.

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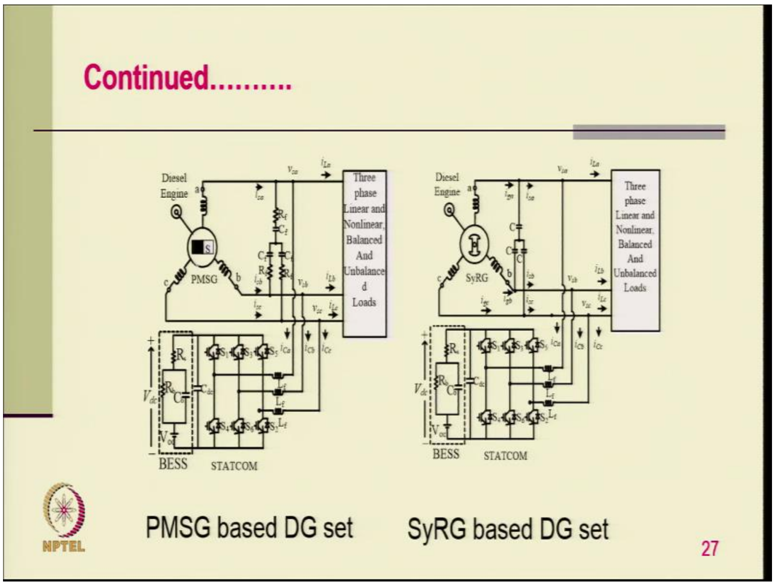

These are the configurations of PMSG and SyRG based DG sets feeding Three phase Three wire (3P3W) loads.

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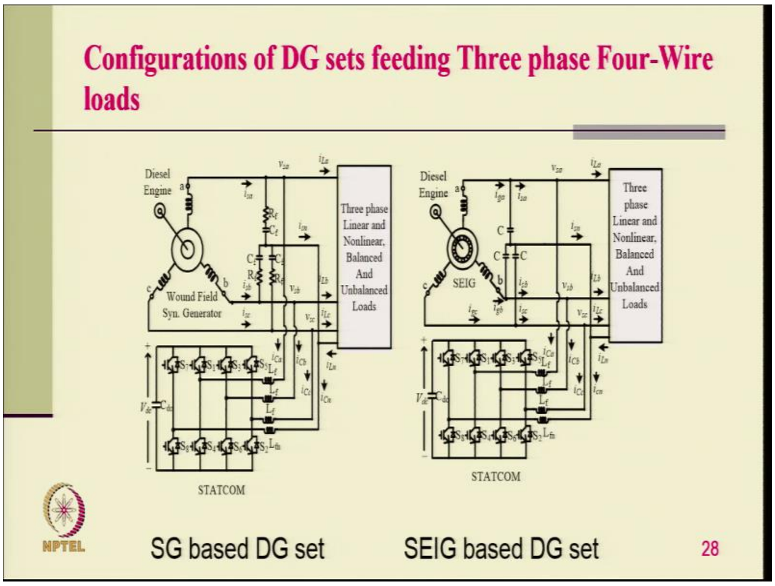

These are the configurations of SG and SEIG based DG sets feeding Three phase Four wire (3P4W) loads.

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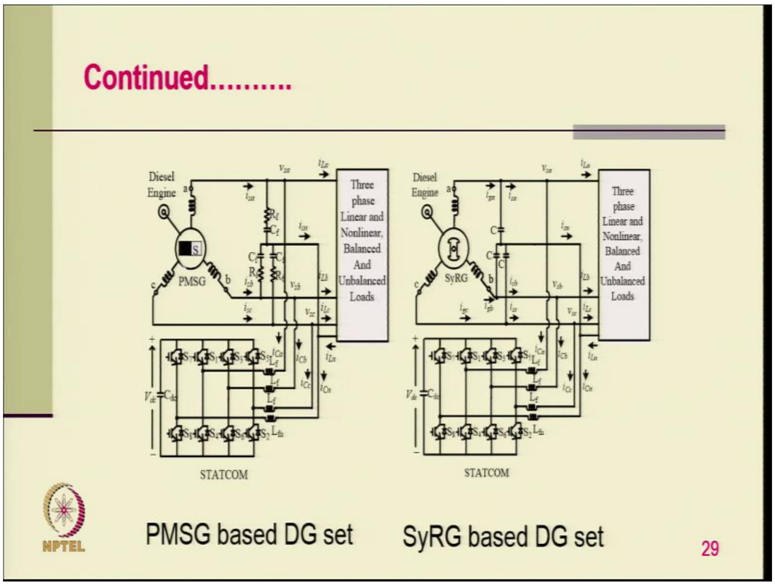

These are the configurations of PMSG and SyRG based DG sets feeding Three phase Four wire (3P4W) loads.

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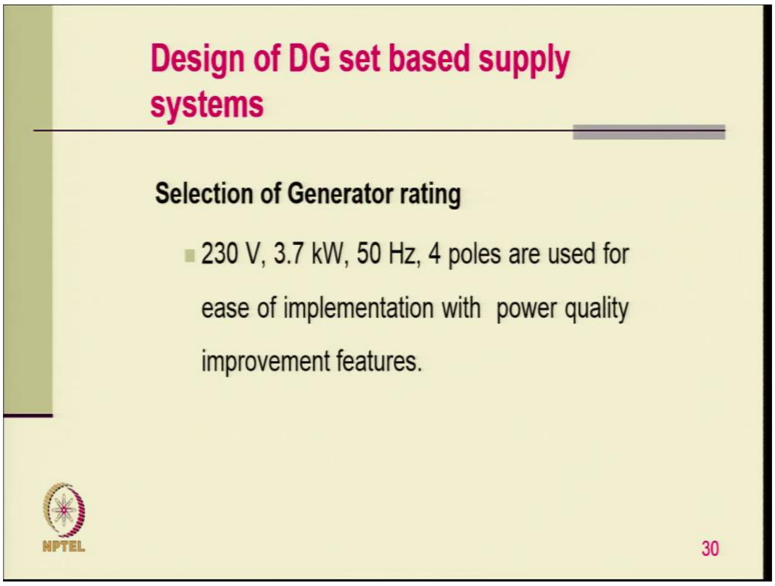

Now, coming to the design part of the DG sets. We have taken a case study that has 3.7 kW, 230 V, 50 Hz, 4 pole generator set is used for the power quality improvement features.

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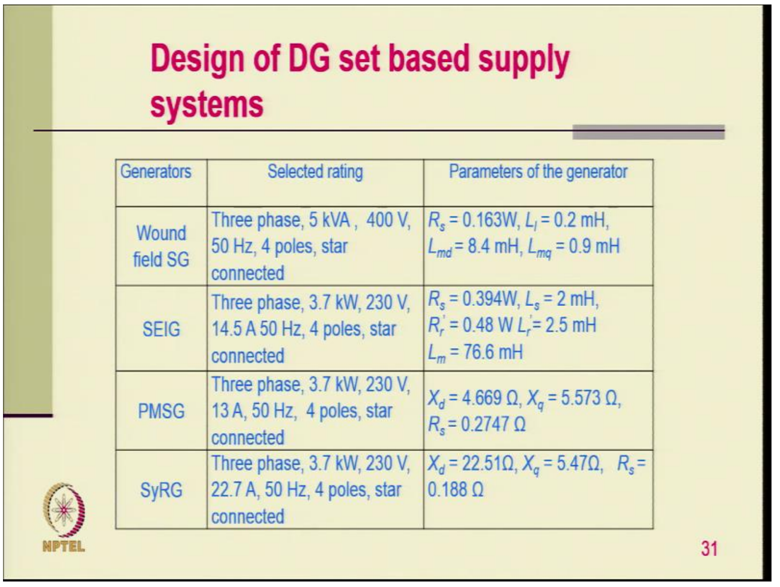

Generators	Selected rating	Parameters of the generator
Wound field SG	Three phase, 5 kVA , 400 V, 50 Hz, 4 poles, star connected	R_s = 0.163W, L_l = 0.2 mH, L_{md} = 8.4 mH, L_{mq} = 0.9 mH
SEIG	Three phase, 3.7 kW, 230 V, 14.5 A 50 Hz, 4 poles, star connected	R_s = 0.394W, L_s = 2 mH, R_r' = 0.48 W L_r'= 2.5 mH L_m = 76.6 mH
PMSG	Three phase, 3.7 kW, 230 V, 13 A, 50 Hz, 4 poles, star connected	X_d = 4.669 Ω, X_q = 5.573 Ω, R_s = 0.2747 Ω
SyRG	Three phase, 3.7 kW, 230 V, 22.7 A, 50 Hz, 4 poles, star connected	X_d = 22.51Ω, X_q = 5.47Ω, R_s = 0.188 Ω

These are the parameters and selected rating of all four machine based DG sets.

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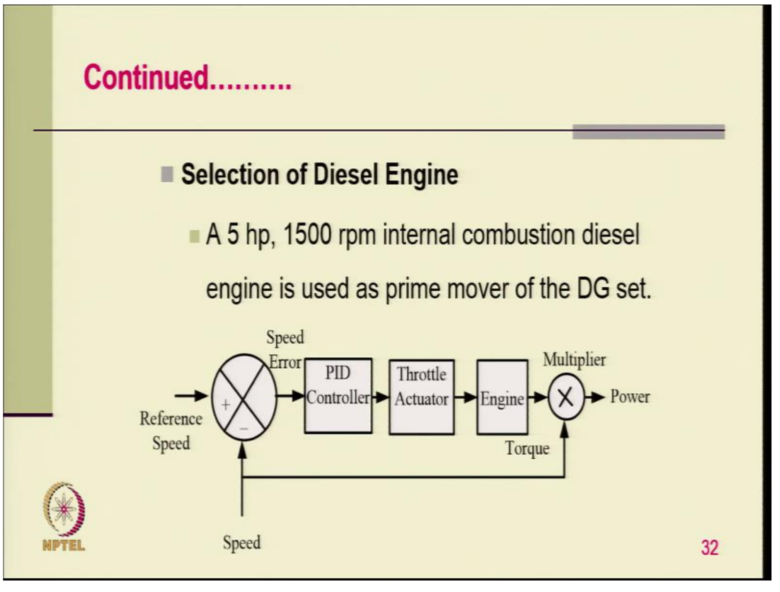

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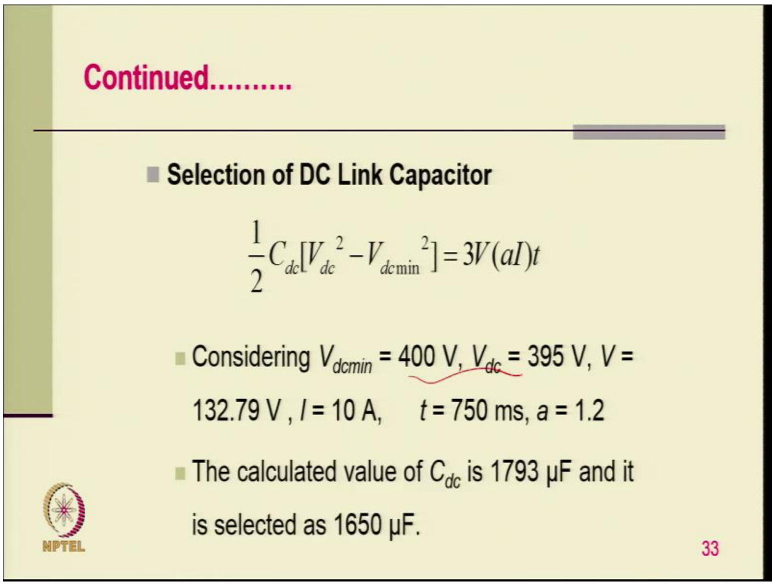

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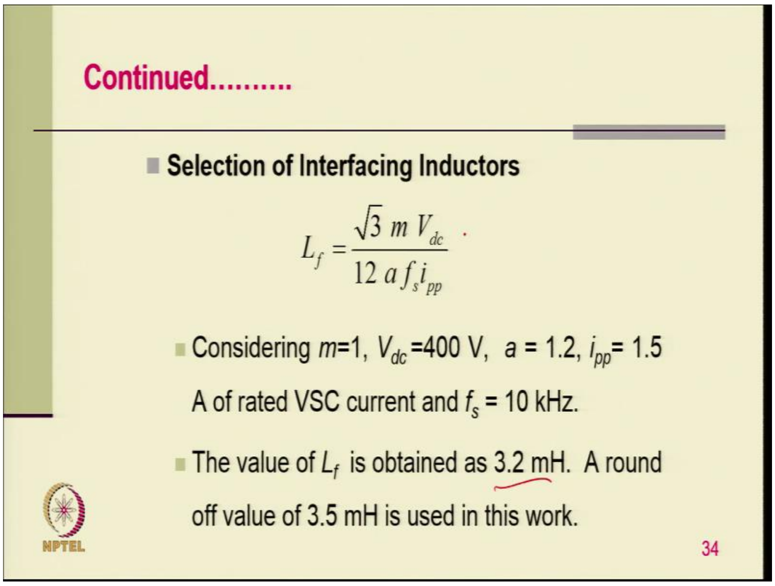

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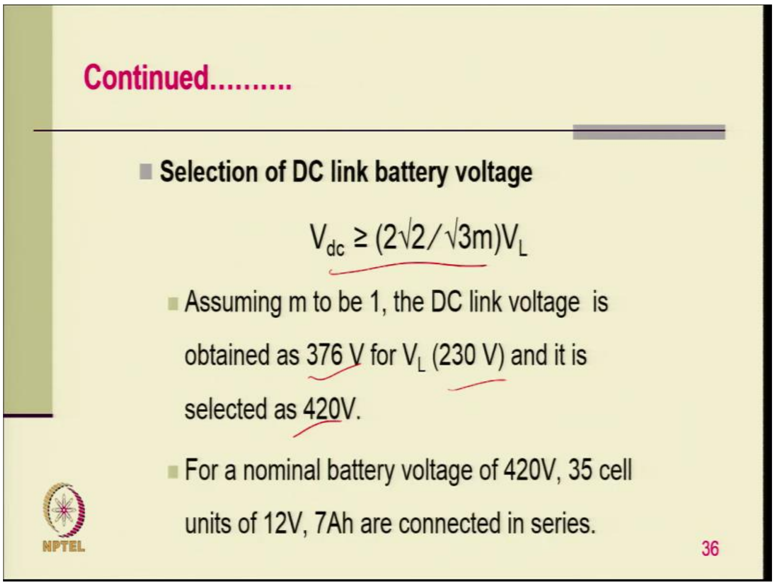

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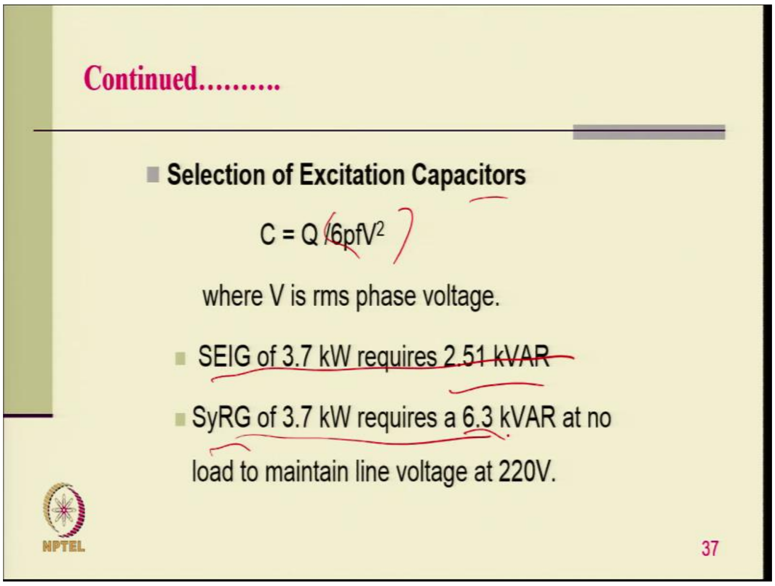

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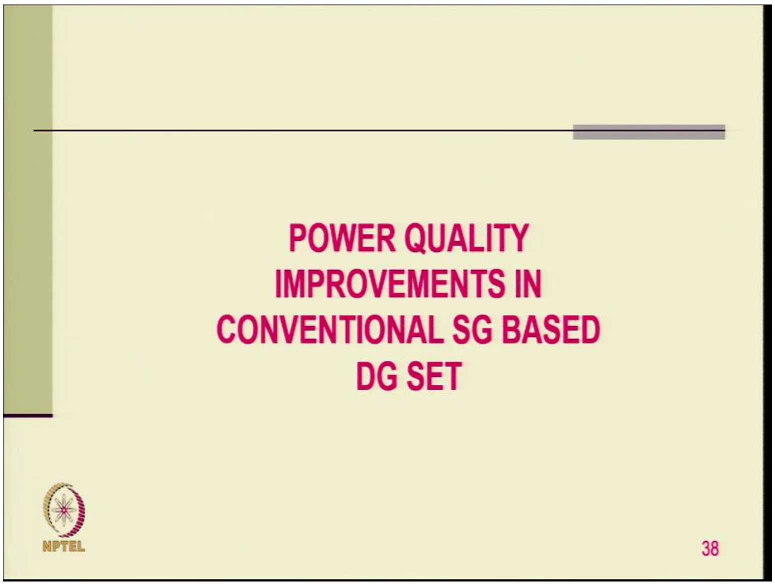

Now, coming to power quality improvement in conventional synchronous generator-based DG set.

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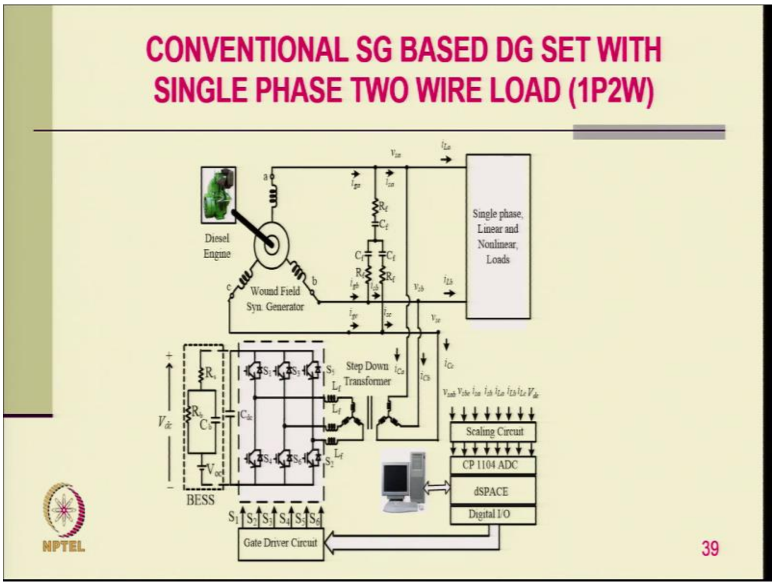

This is the typical configuration of conventional SG based DG set with 1-Phase two wire load (1P2W).

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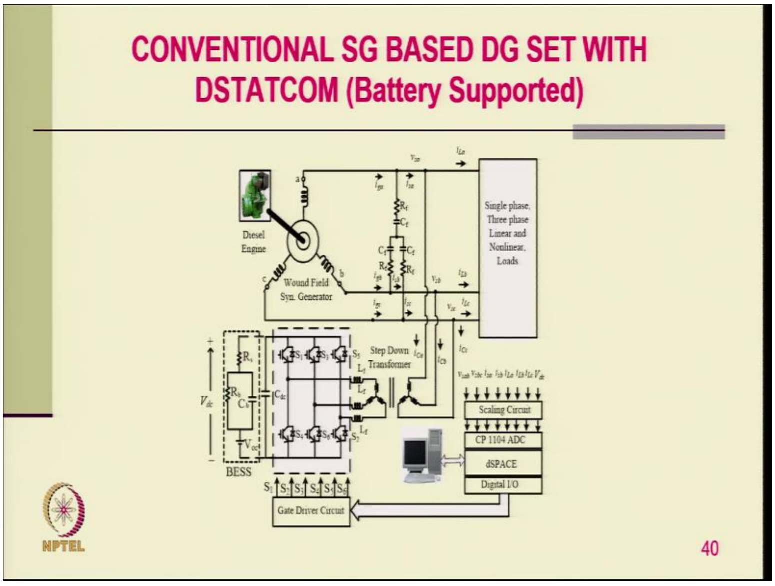

This is the typical configuration of conventional SG based DG set with battery supported DSTATCOM.

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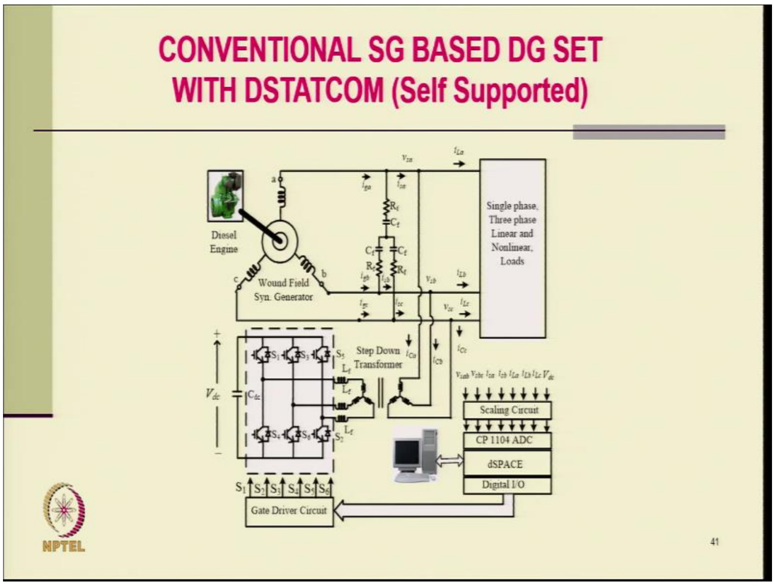

This is the typical configuration of conventional SG based DG set with self supported DSTATCOM.

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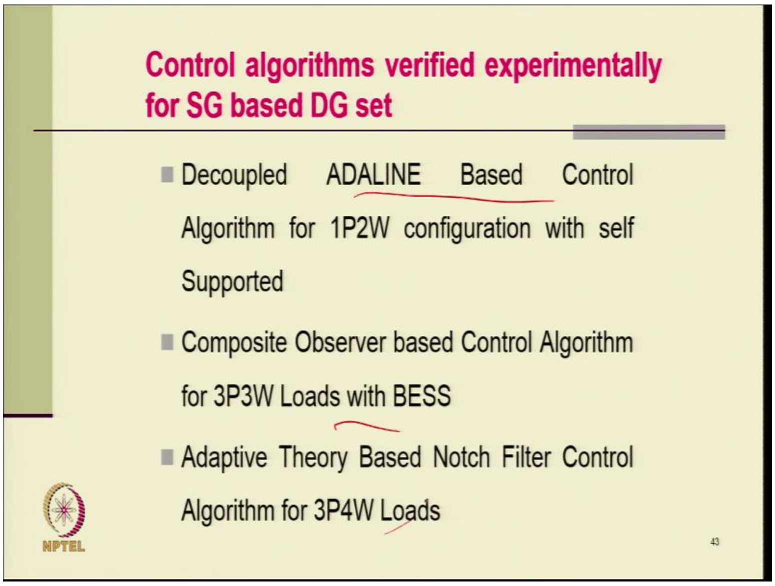

These are the control algorithms which has been verified experimentally for the control of conventional SG based DG sets.

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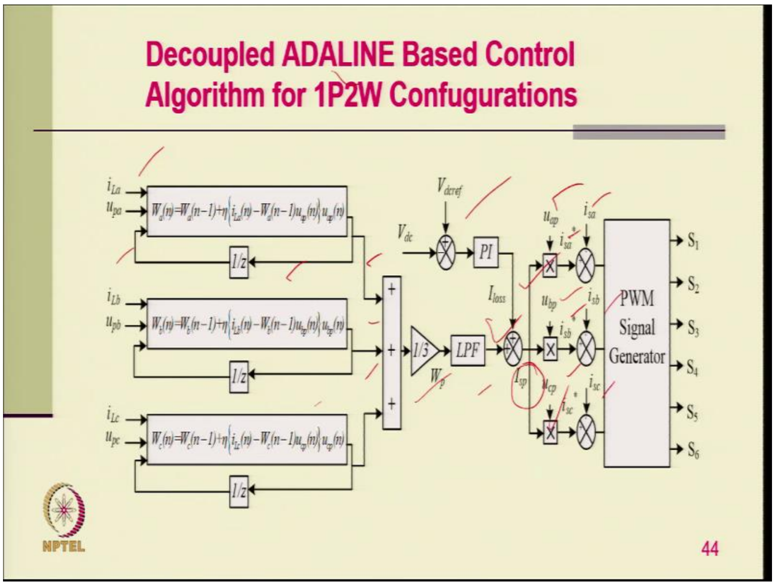

This is the block diagram of decoupled ADALINE based control algorithm for 1P2W configurations.

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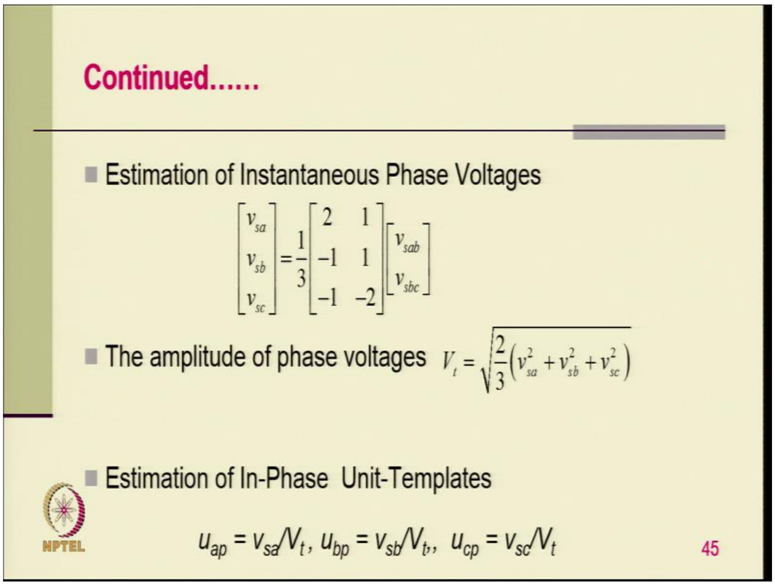

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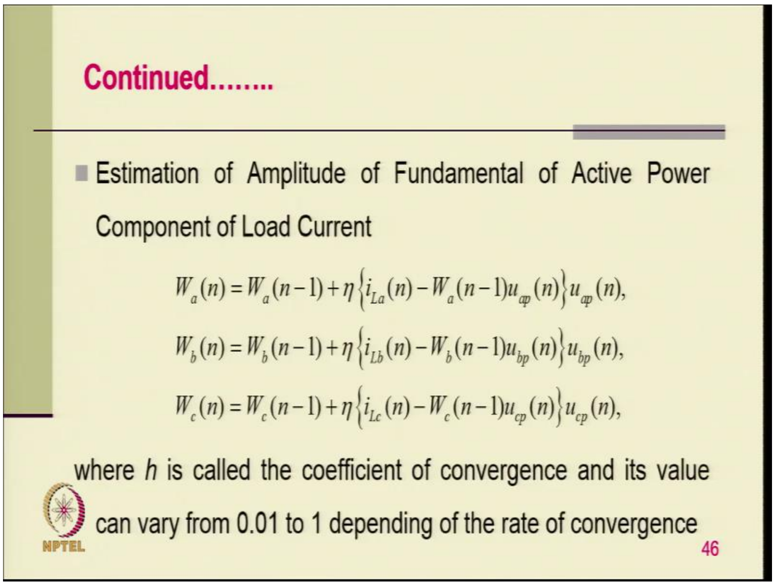

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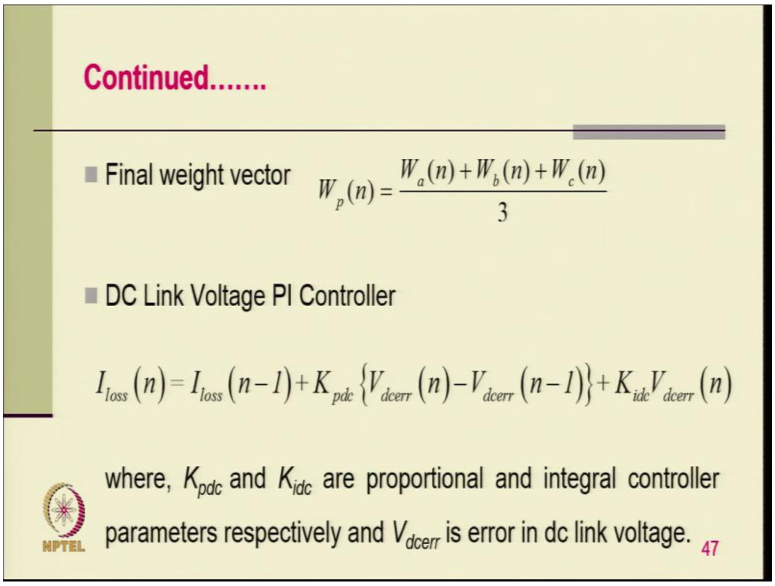

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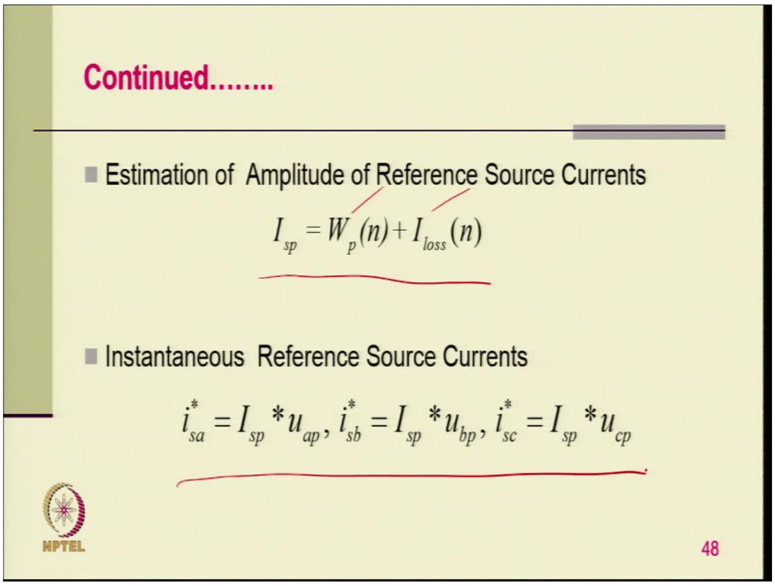

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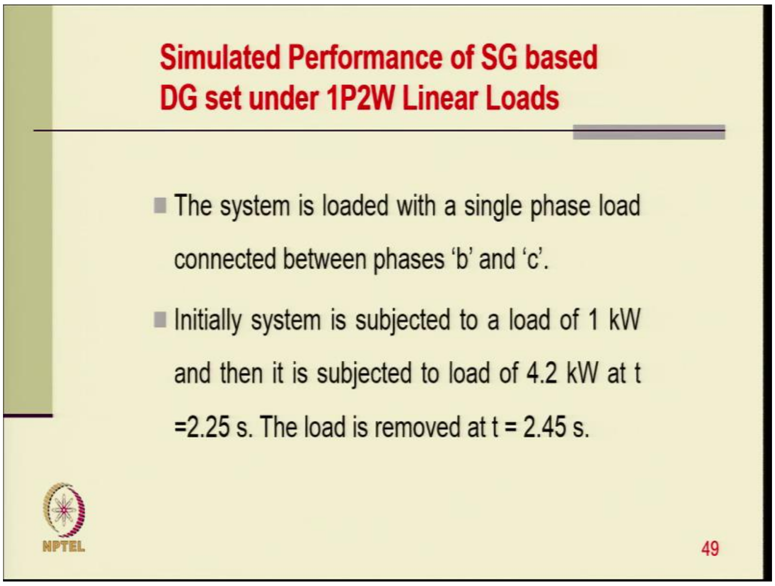

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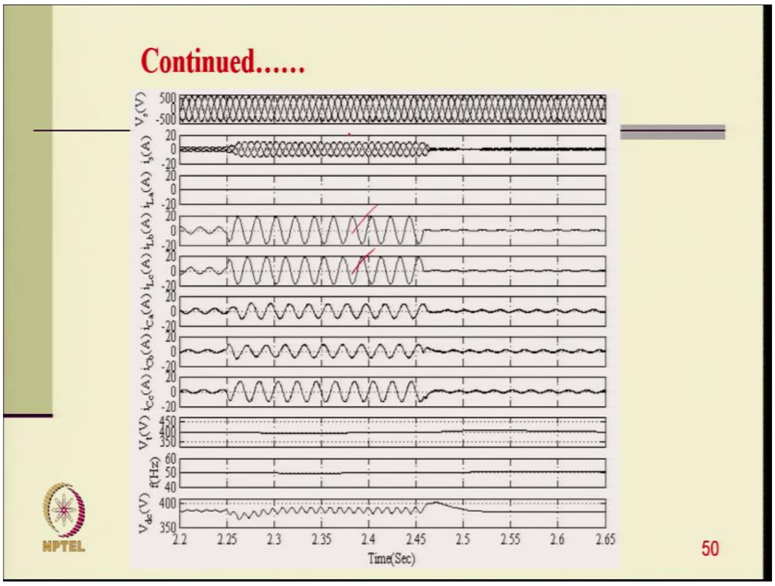

This is the simulated performance of SG based DG sets under 1P2W linear loads.

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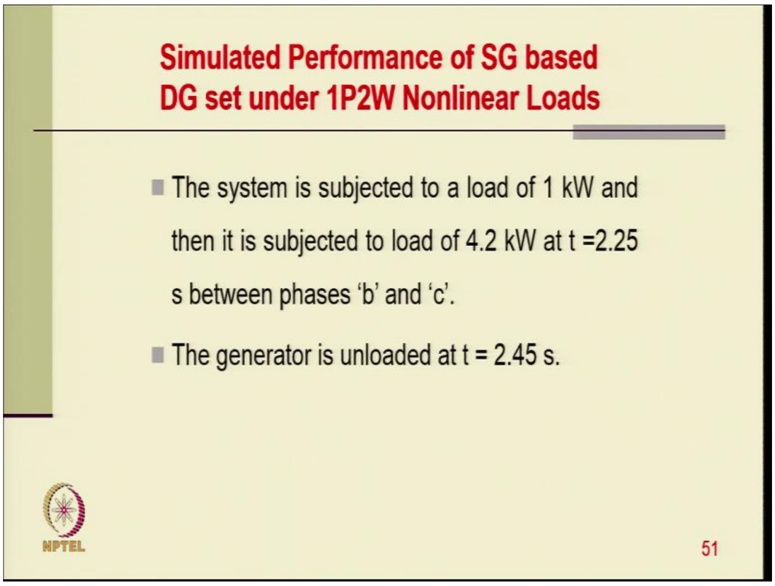

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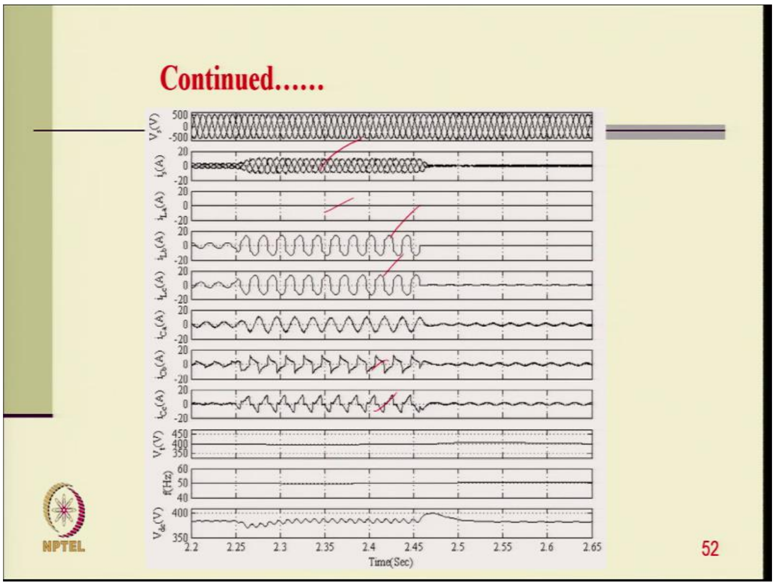

This is the simulated performance of SG based DG sets under 1P2W non-linear loads.

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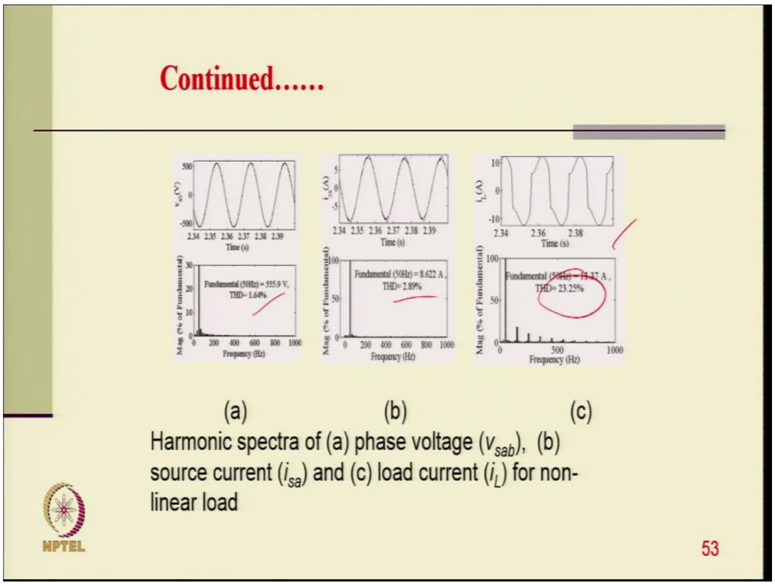

And these are the harmonic spectrum. The load current have a quite high THD, but you can see the generator current THD is quite low as well as voltage THD is also quite low, at the point of common coupling. But if you do not put this compensator certainly, the load currents will become your generator current.

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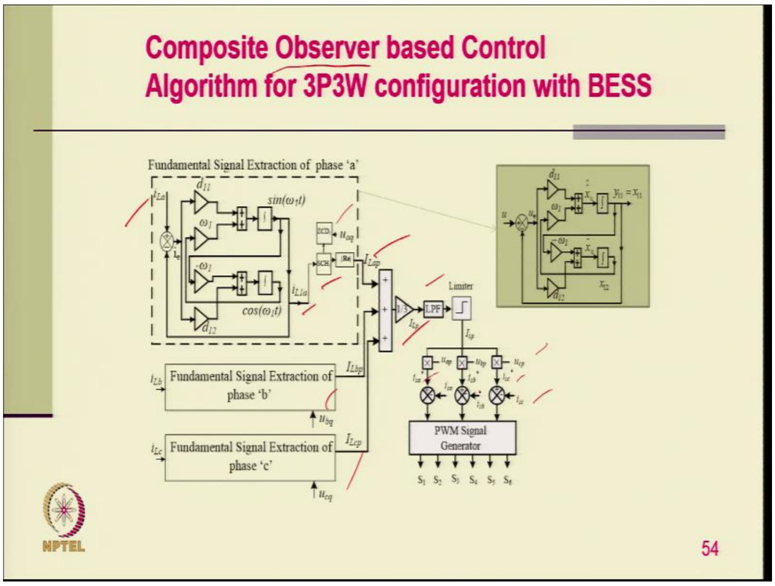

This is another control algorithm.

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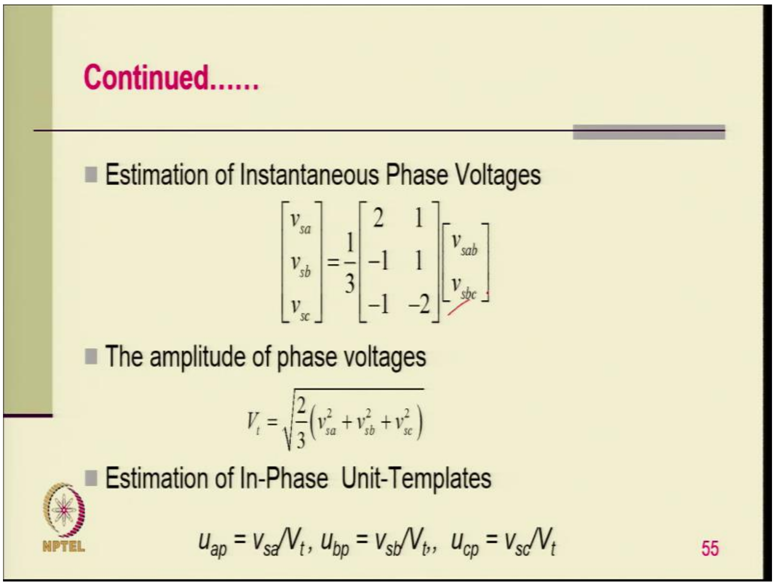

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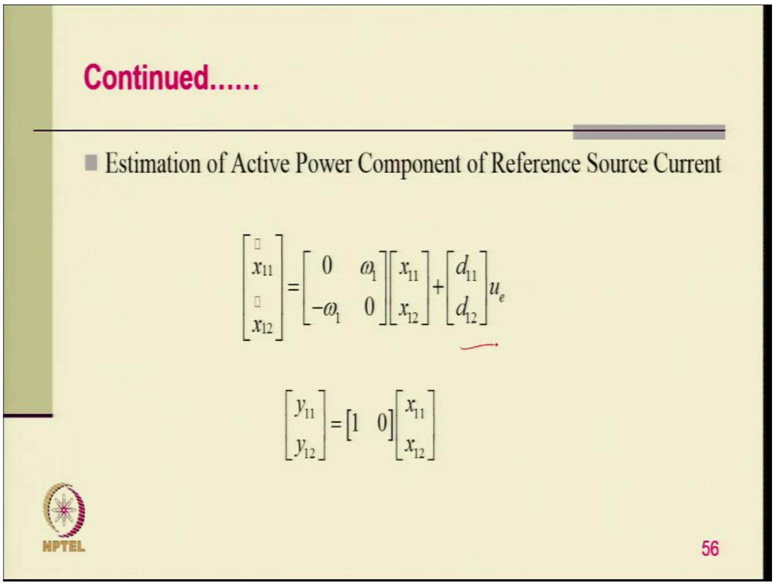

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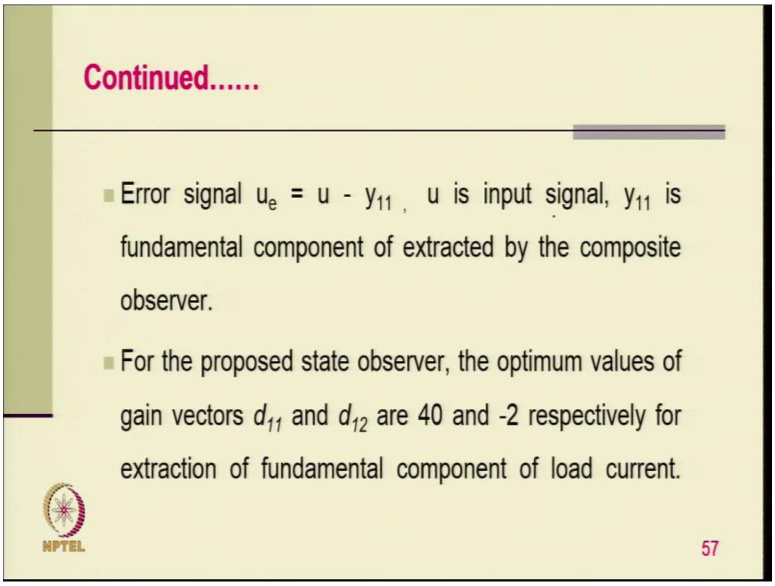

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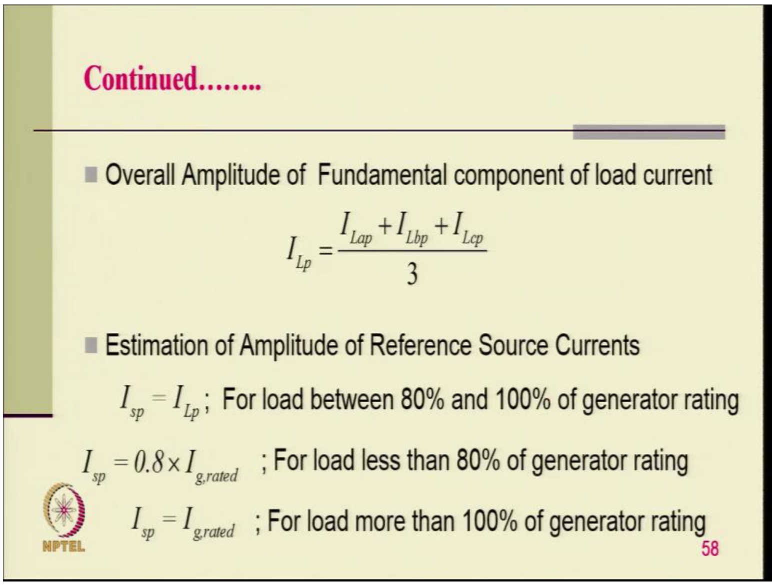

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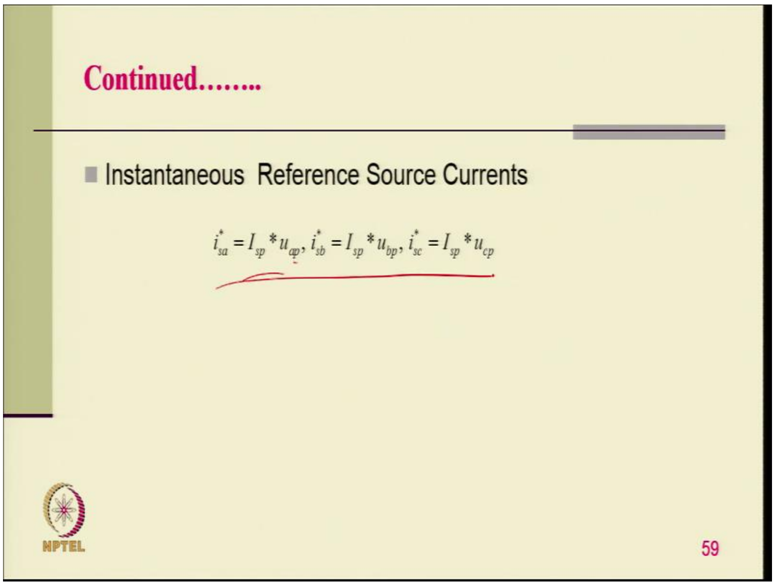

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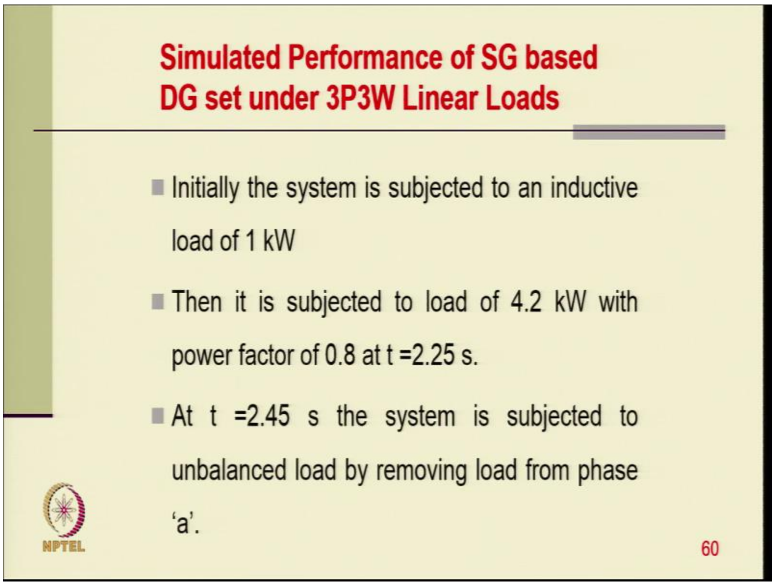

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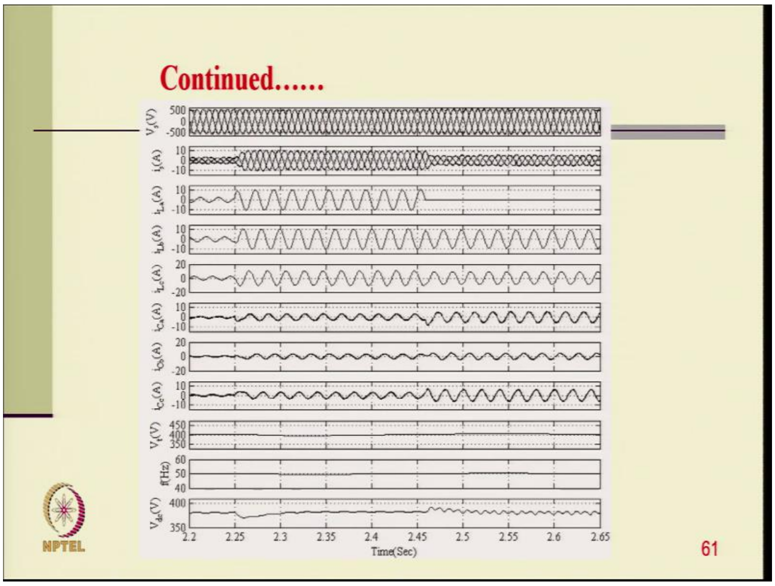

These are the simulated performance of SG based DG set under 3P3W linear loads.

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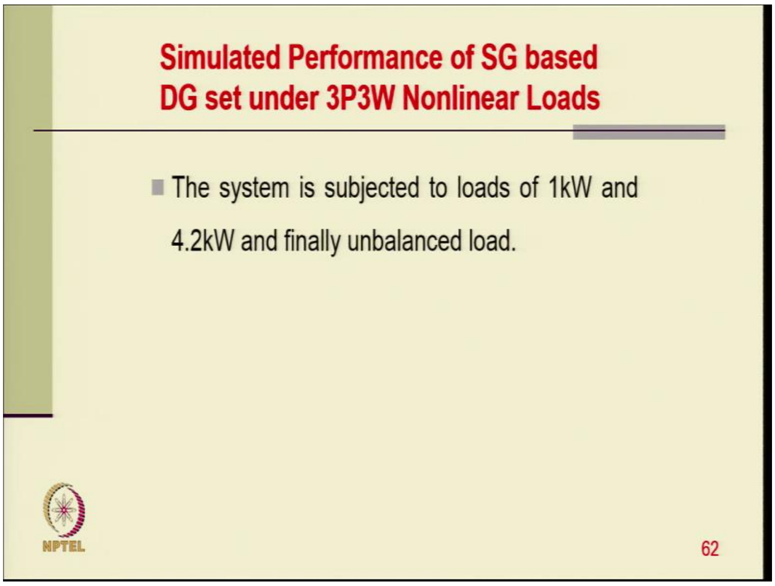

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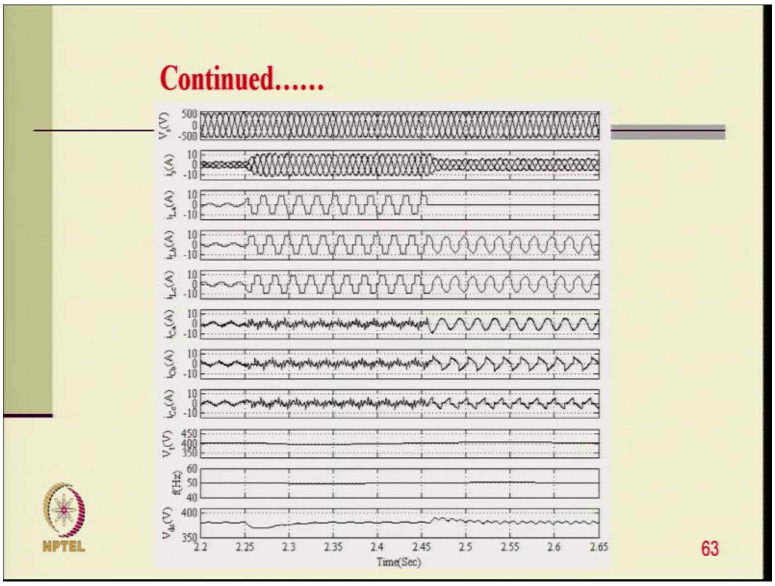
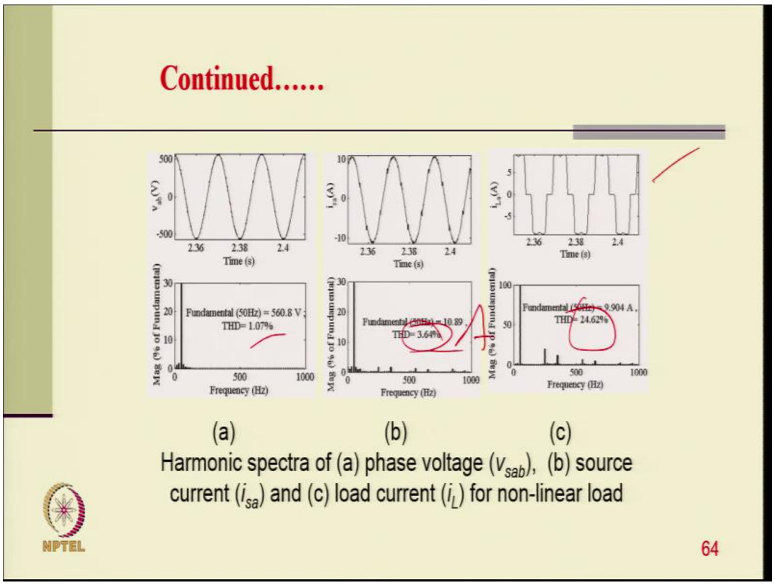


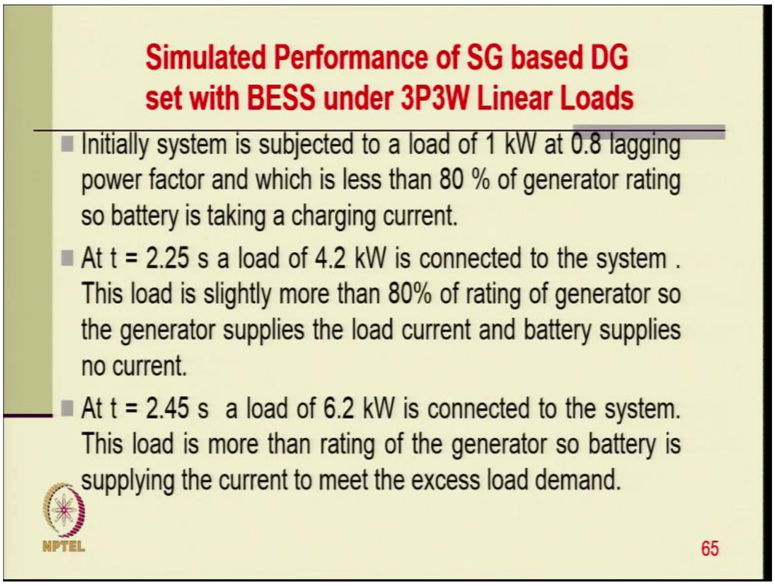
These are the simulated performance of SG based DG set under 3P3W non-linear loads.

(Refer Slide Time: 23:35)

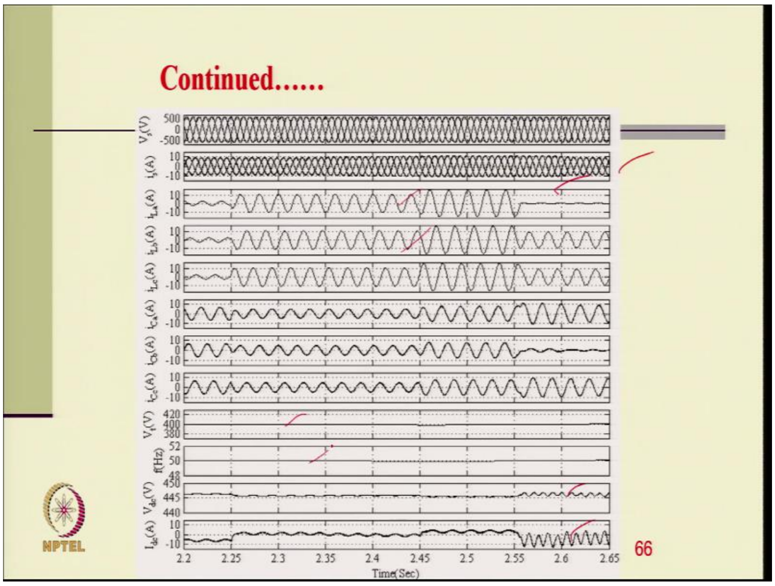


And these are harmonic the spectrum, when the load current THD is 24%; you are able to get the generator current THD only typically of 3.64% and the voltage THD is maintained 1.07%.

(Refer Slide Time: 24:00)

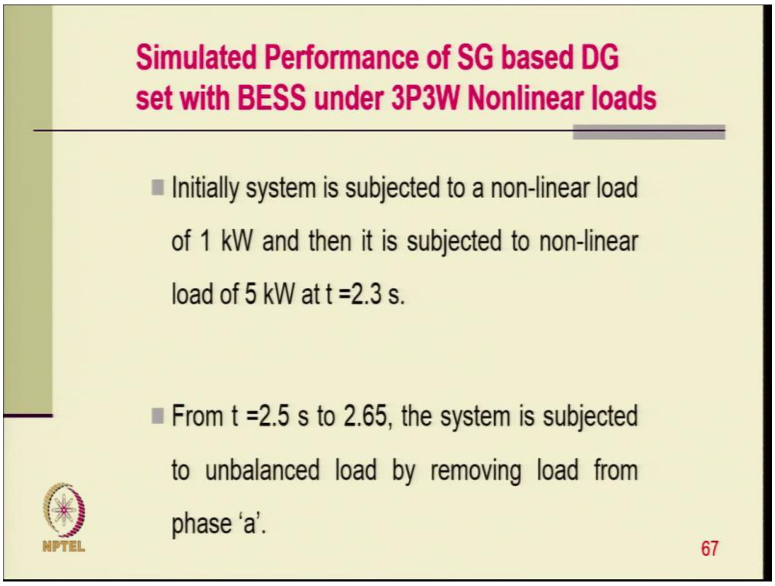


(Refer Slide Time: 24:10)

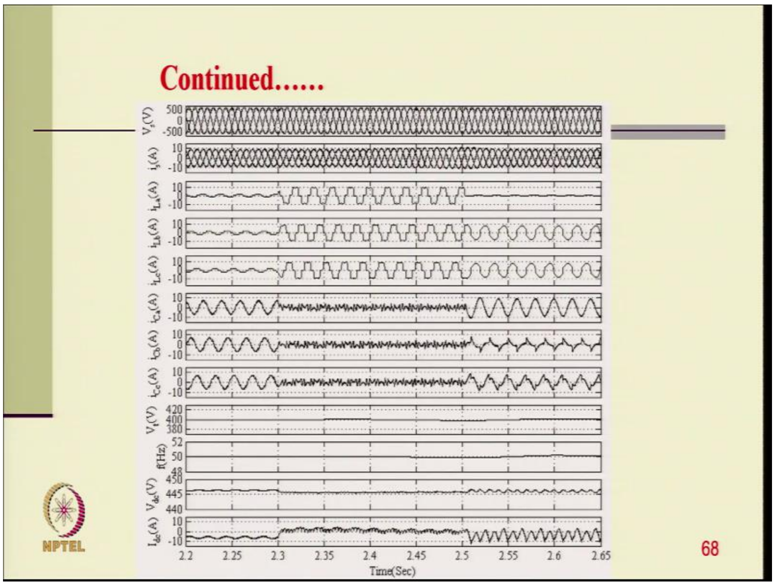


These are the simulated performance of SG based DG set with BES system under 3P3W linear loads.

(Refer Slide Time: 24:32)

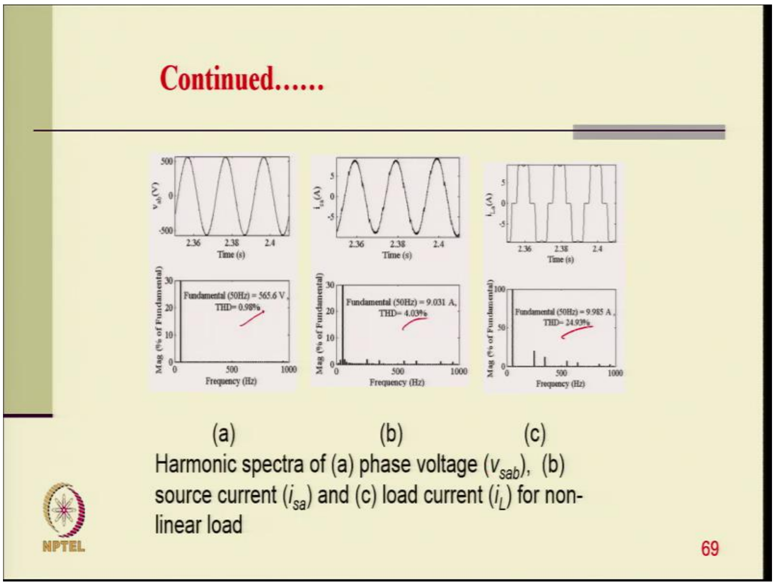


(Refer Slide Time: 24:45)

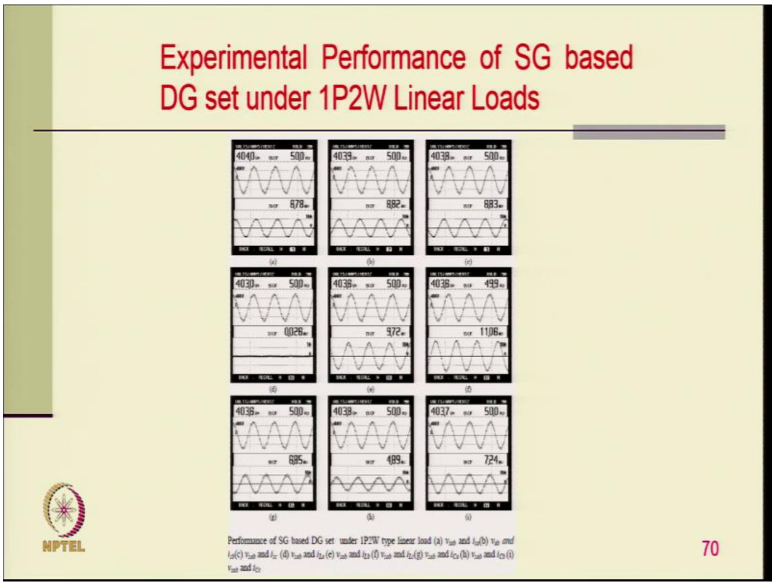


These are the simulated performance of SG based DG set with BES system under 3P3W non linear loads.

(Refer Slide Time: 25:05)

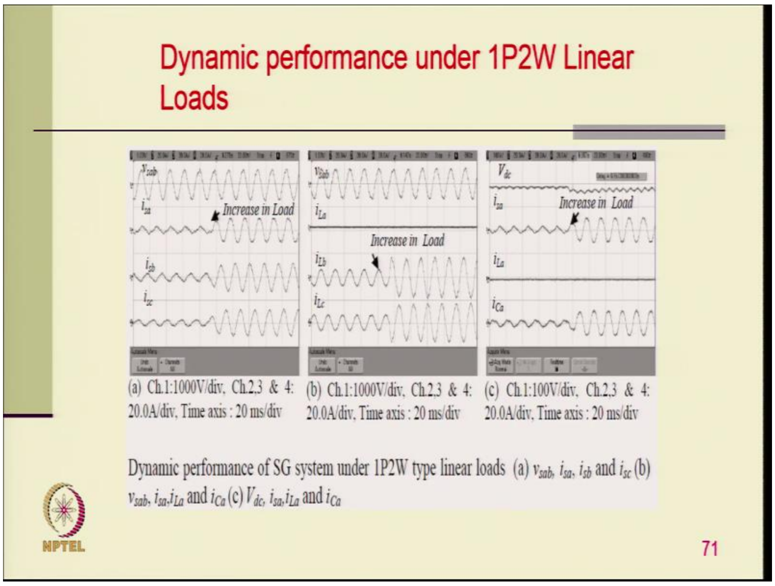


(Refer Slide Time: 25:15)



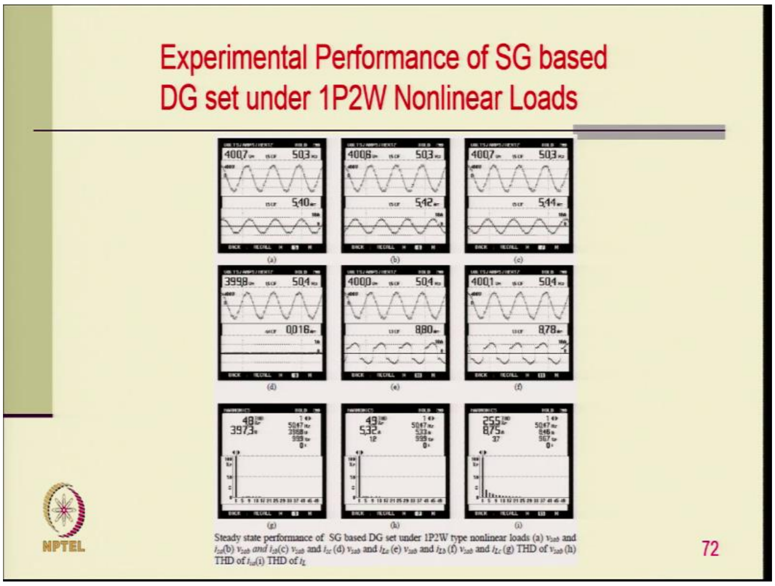
This is the experimental performance of SG based DG set under 1P2W linear loads.

(Refer Slide Time: 25:25)



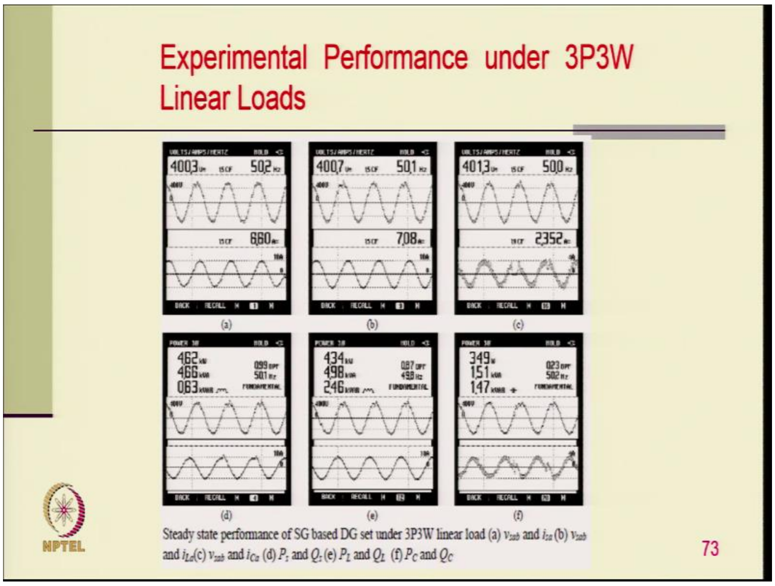
This is the experimental performance of SG based DG set under dynamic condition with 1P2W linear loads.

(Refer Slide Time: 25:44)



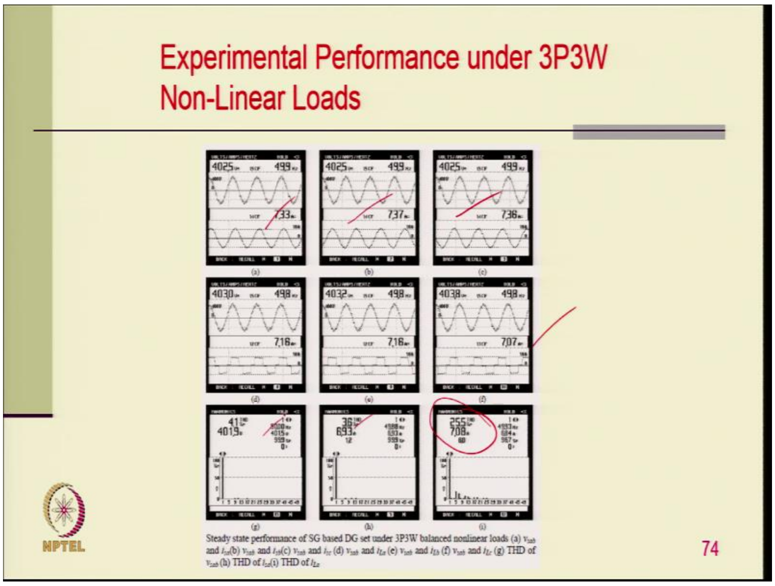
This is the experimental performance of SG based DG set under 1P2W non-linear loads.

(Refer Slide Time: 26:06)



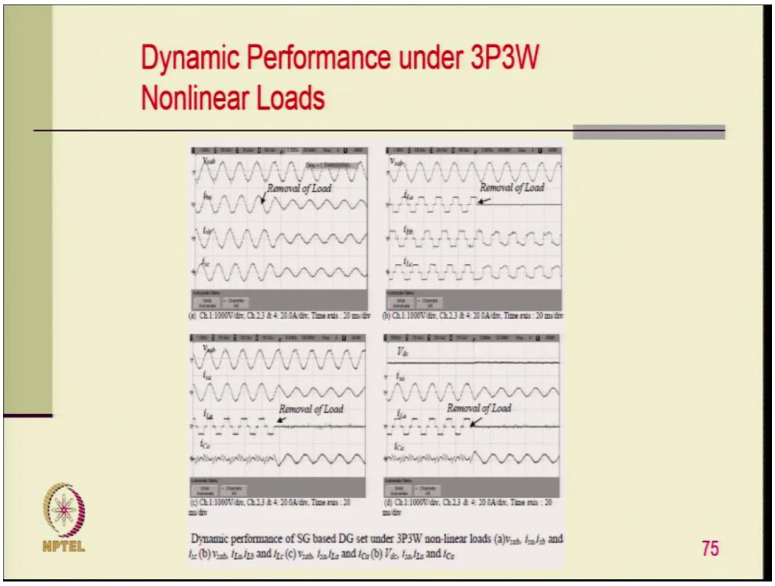
This is the experimental performance of SG based DG set under 3P3W linear loads.

(Refer Slide Time: 26:27)



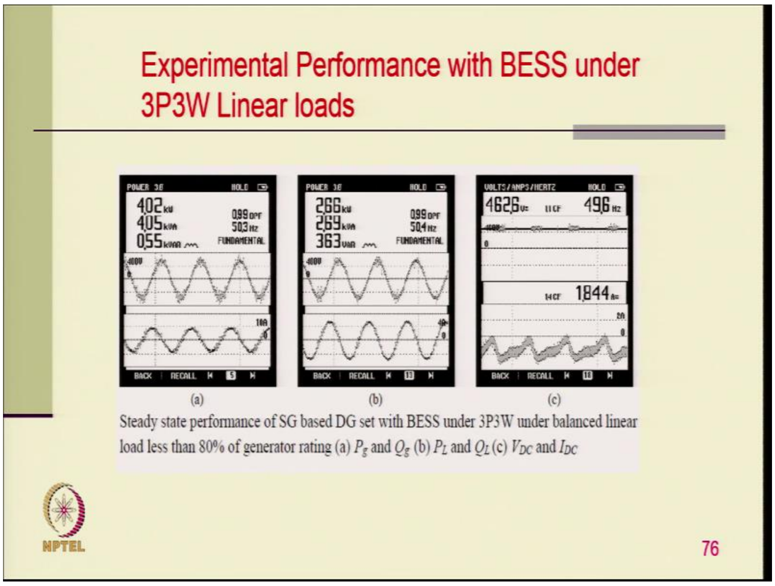
This is the experimental performance of SG based DG set under 3P3W non-linear loads.

(Refer Slide Time: 26:43)



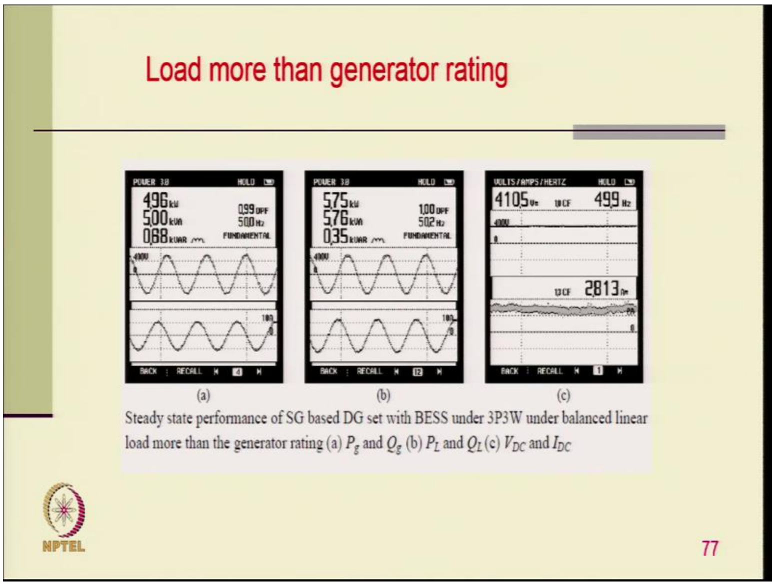
This is the experimental performance of SG based DG set under dynamic condition with 3P3W linear loads.

(Refer Slide Time: 26:55)



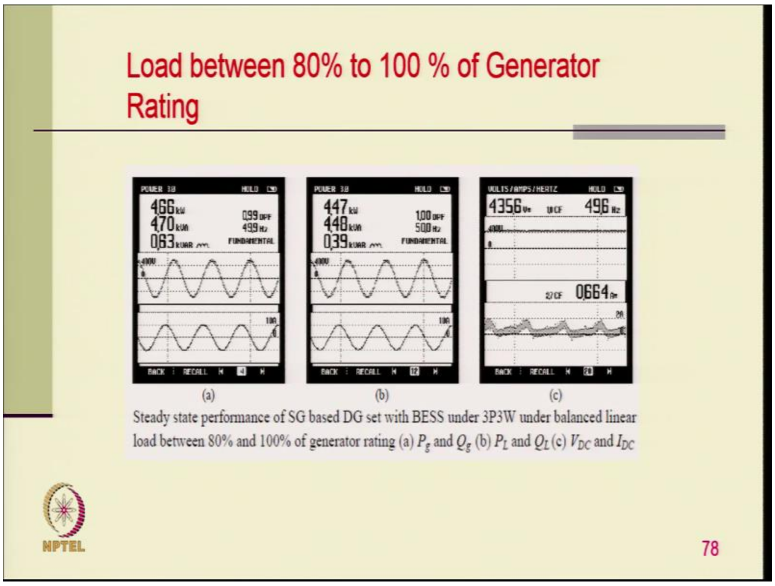
This is the experimental performance of SG based DG with BESS under 3P3W linear loads.

(Refer Slide Time: 27:04)



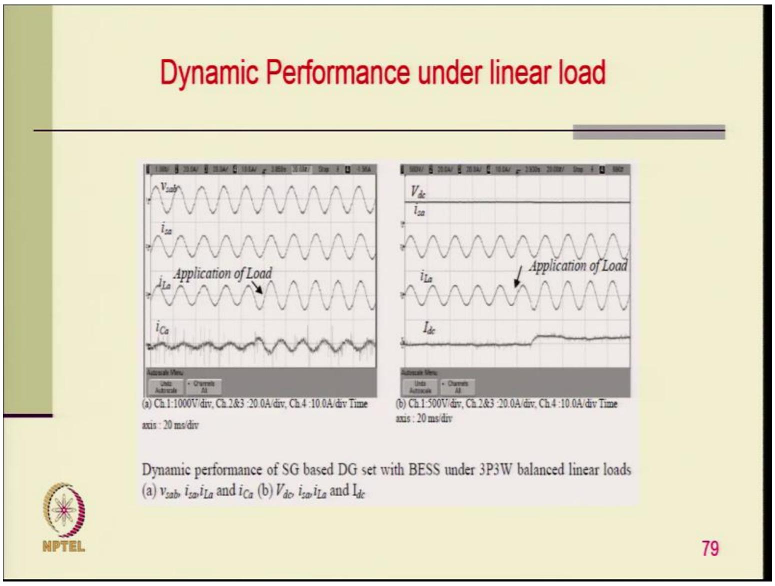
This is the experimental performance of SG based DG set under load more than generator rating.

(Refer Slide Time: 27:22)



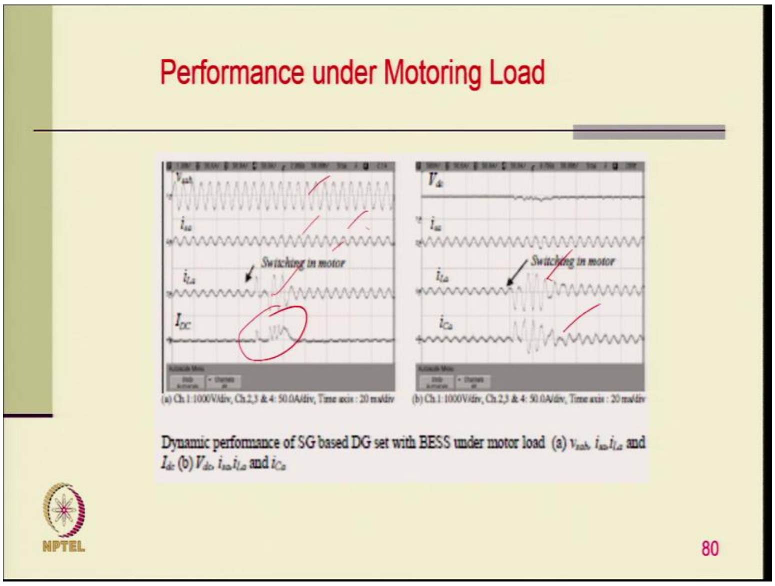
This is the experimental performance of SG based DG set under load between 80% to 100% generator rating.

(Refer Slide Time: 27:30)



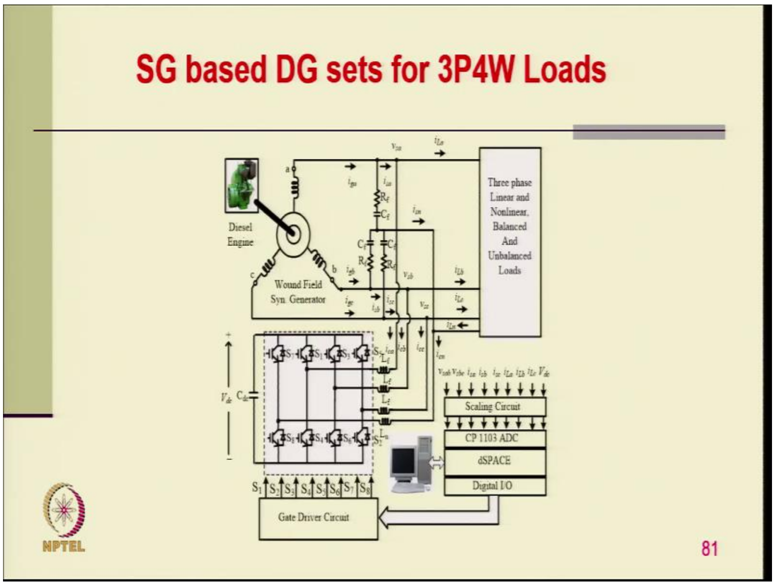
This is the experimental performance of SG based DG set (with BESS) under dynamic condition with 3P3W linear loads.

(Refer Slide Time: 27:40)



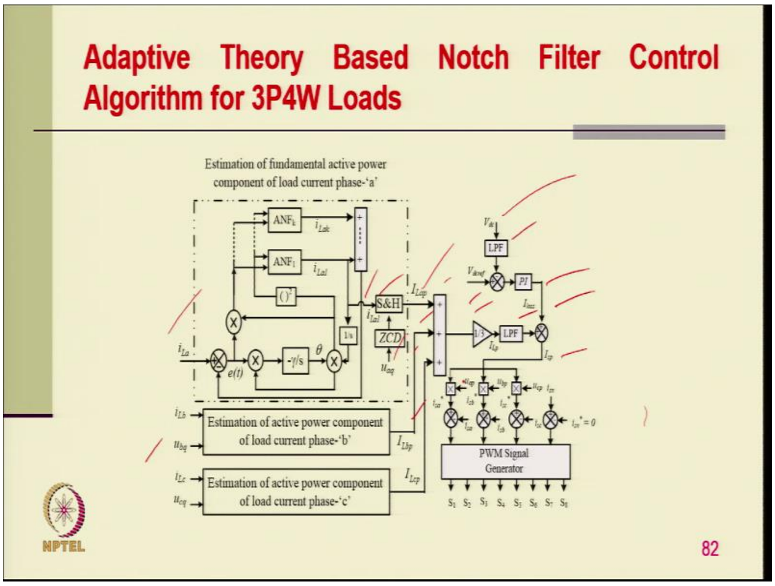
This is the experimental performance of SG based DG set under motoring loads.

(Refer Slide Time: 28:11)



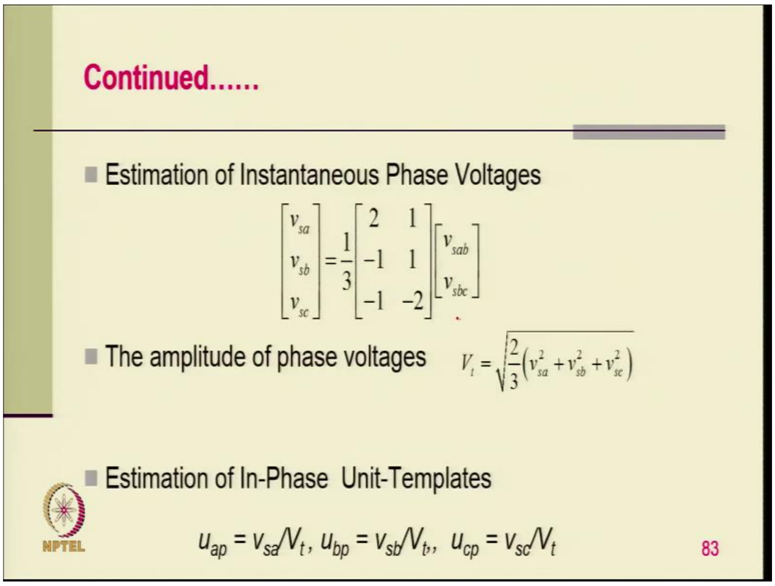
Now, coming to another configuration. This is the circuit configuration of SG based DG sets for 3P4W loads.

(Refer Slide Time: 28:30)

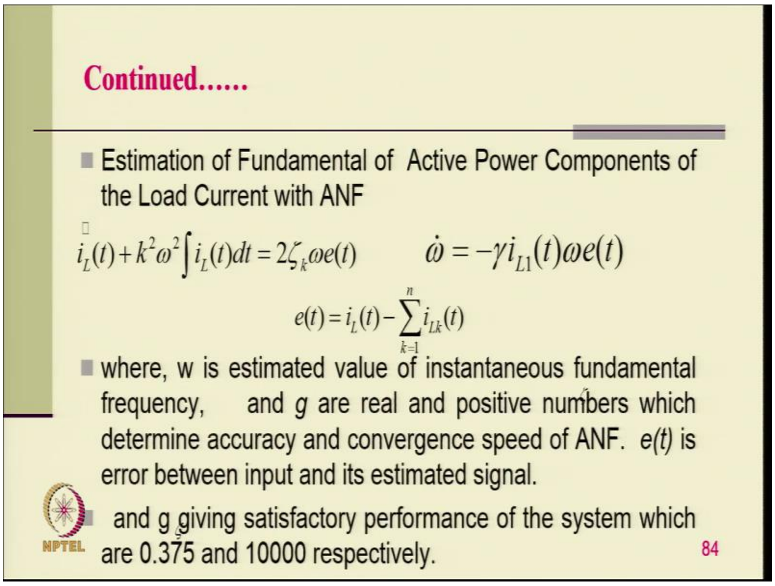


This is the control algorithm based on adaptive theory based notch filter controller.

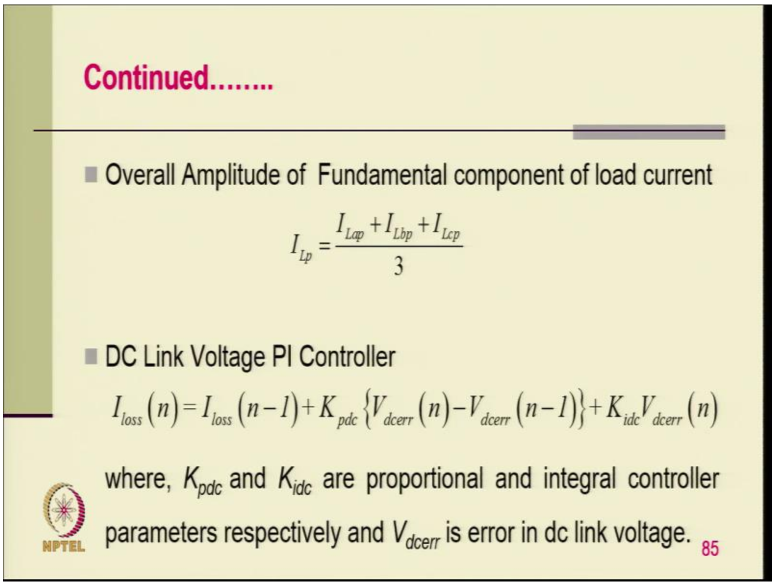
(Refer Slide Time: 29:18)



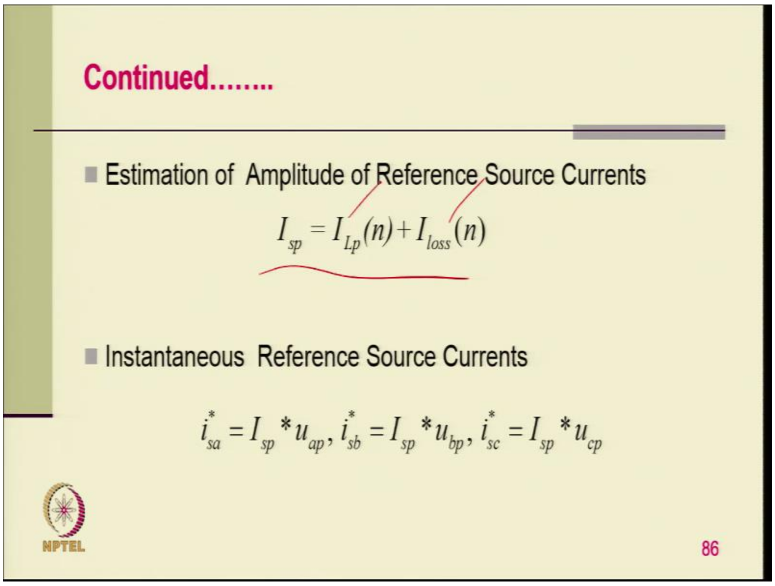
(Refer Slide Time: 29:27)



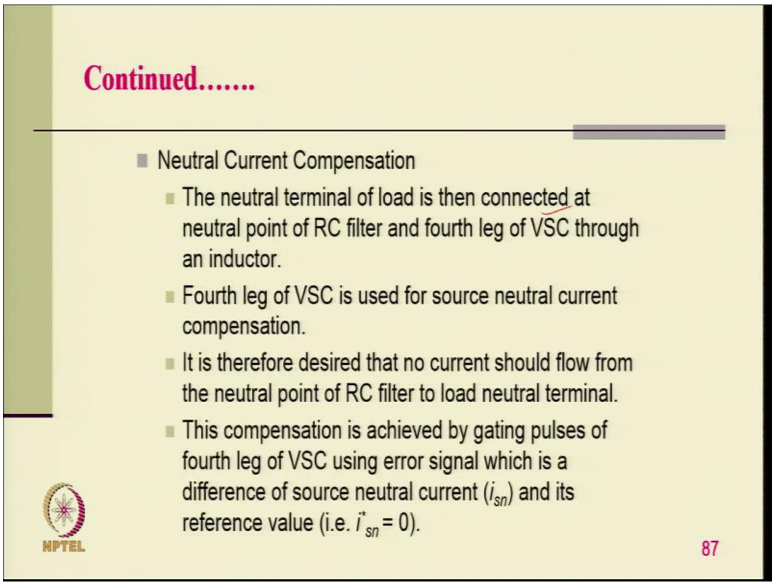
(Refer Slide Time: 29:41)



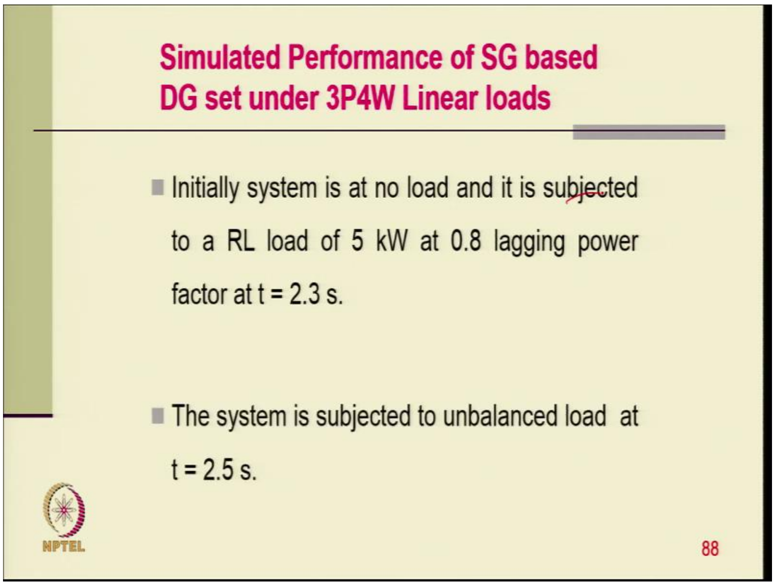
(Refer Slide Time: 29:59)



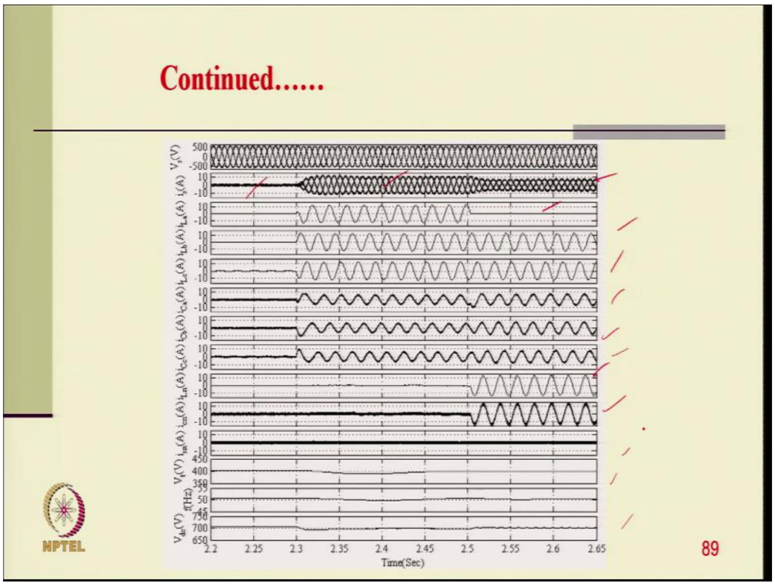
(Refer Slide Time: 30:26)



(Refer Slide Time: 30:41)

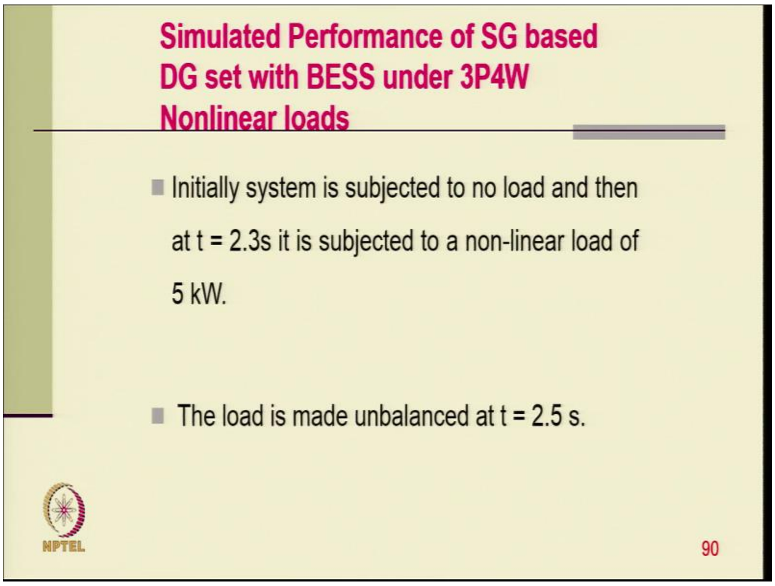


(Refer Slide Time: 30:50)

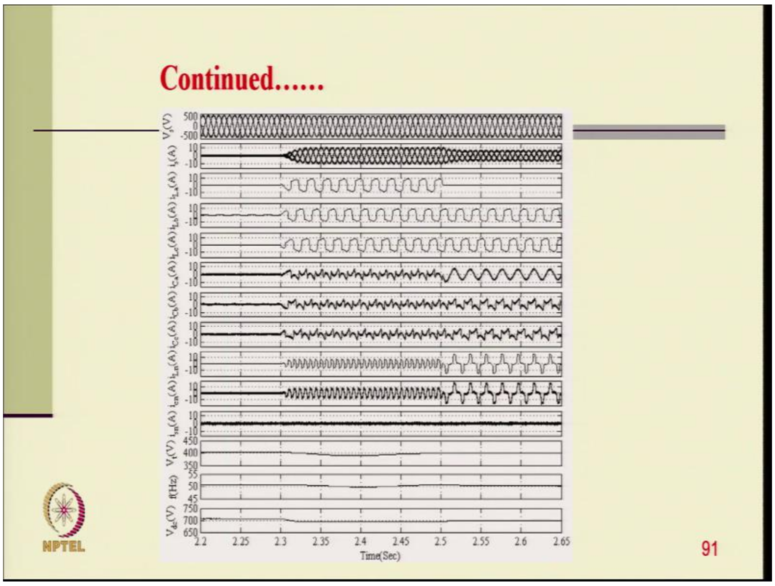


This is the simulated performance of SG based DG set under 3P4W linear loads.

(Refer Slide Time: 31:27)

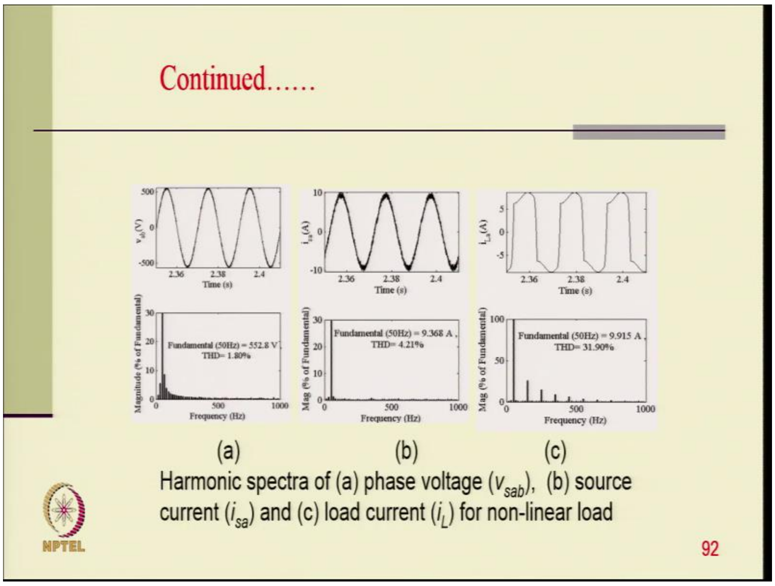


(Refer Slide Time: 31:29)



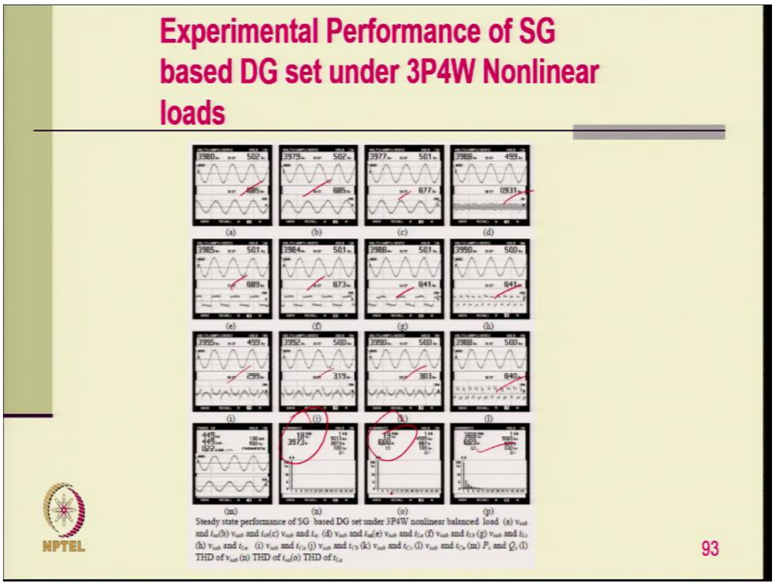
This is the simulated performance of SG based DG set under 3P4W non-linear loads.

(Refer Slide Time: 31:52)



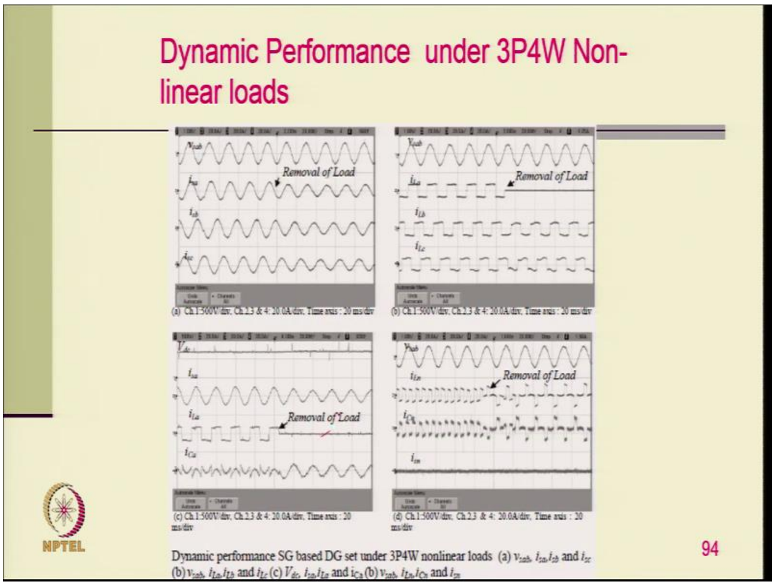
And you can see the THD of the load current is 31.9%, where the THD of your generator current is only 4.2% and it is a 1.8 % THD of the terminal voltage PCC voltage of the generator.

(Refer Slide Time: 32:07)



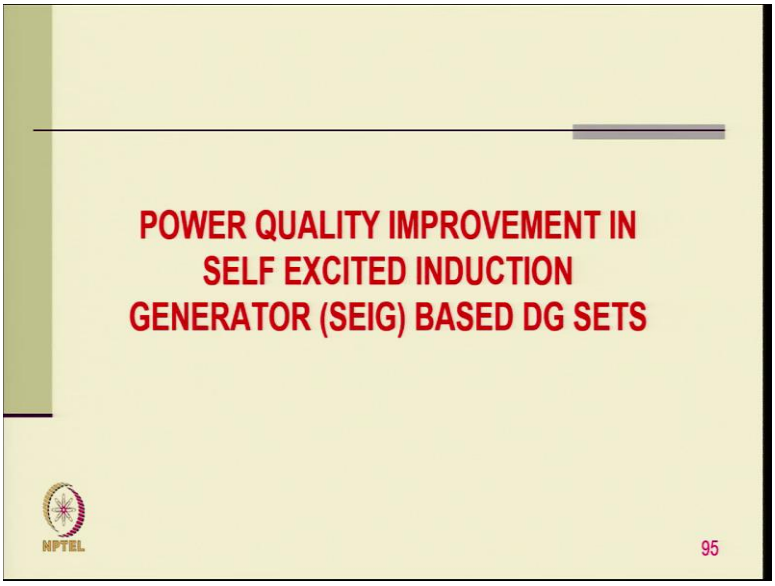
This is the experimental performance of SG based DG set under 3P4W nonlinear loads.

(Refer Slide Time: 32:35)

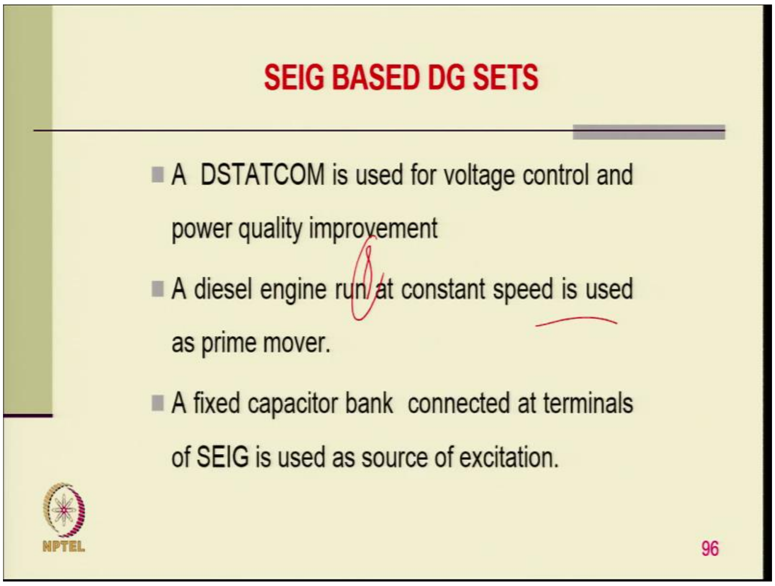


This is the experimental performance of SG based DG set under 3P4W nonlinear loads under dynamic conditions.

(Refer Slide Time: 32:50)

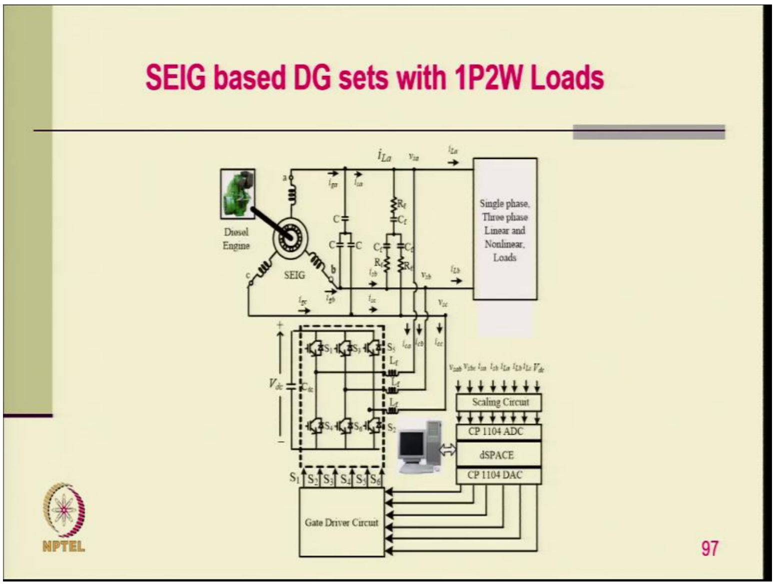


(Refer Slide Time: 32:58)

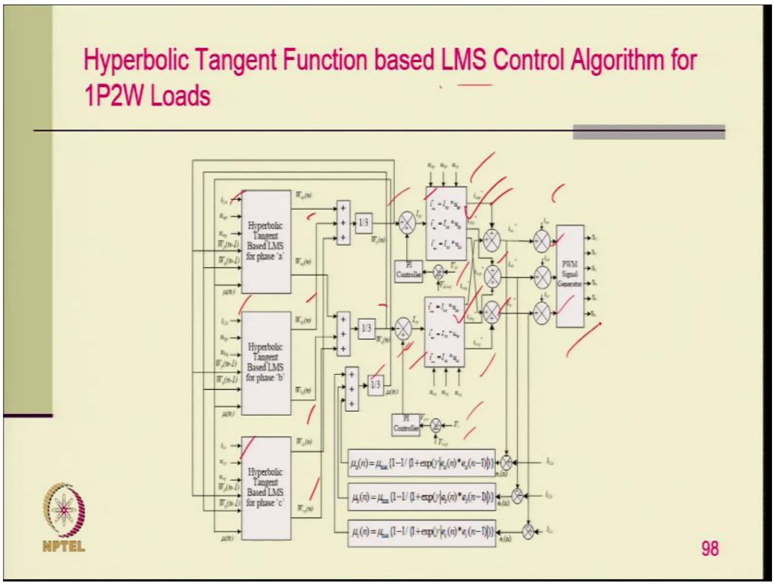


Now, coming to now performance of your power quality improvement in self excited induction generator, in based DG set. In self excited induction generator if you look into, we can use the DSTATCOM voltage. Here, we have to regulate the voltage also voltage control, because there is no other way as well as we have to improve the power quality by load balancing harmonic elimination and diesel engine runs at typically at constant speed. And the fixed capacitor bank is connected at the terminal of SEIG.

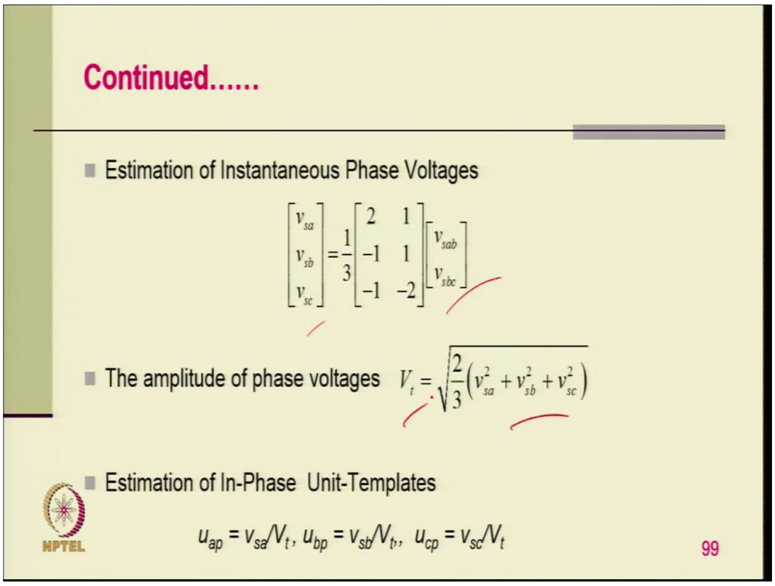
(Refer Slide Time: 33:18)



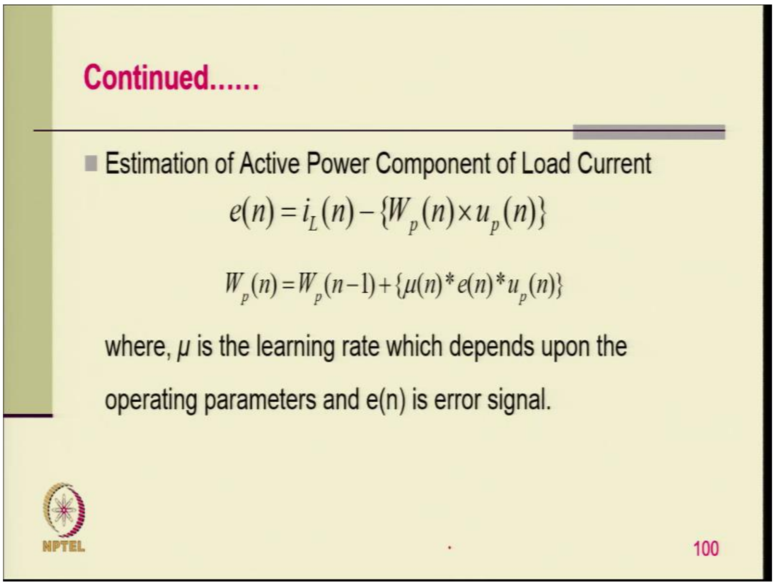
(Refer Slide Time: 33:48)



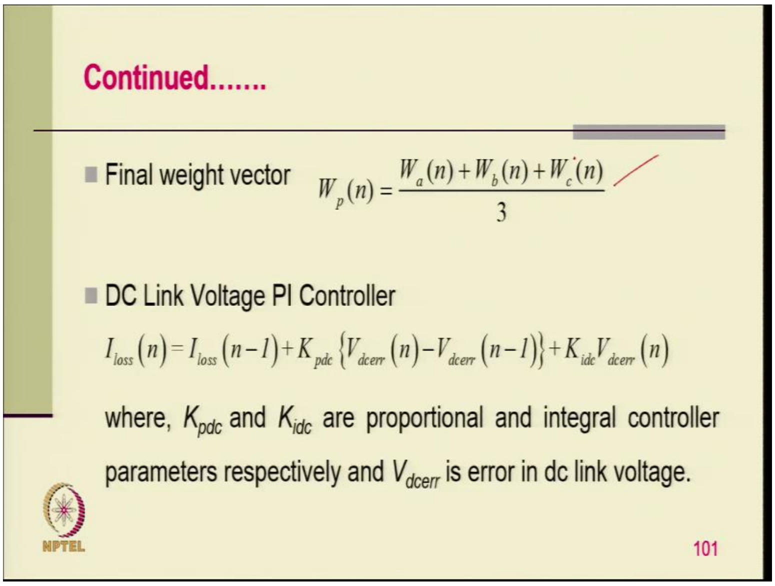
(Refer Slide Time: 34:49)



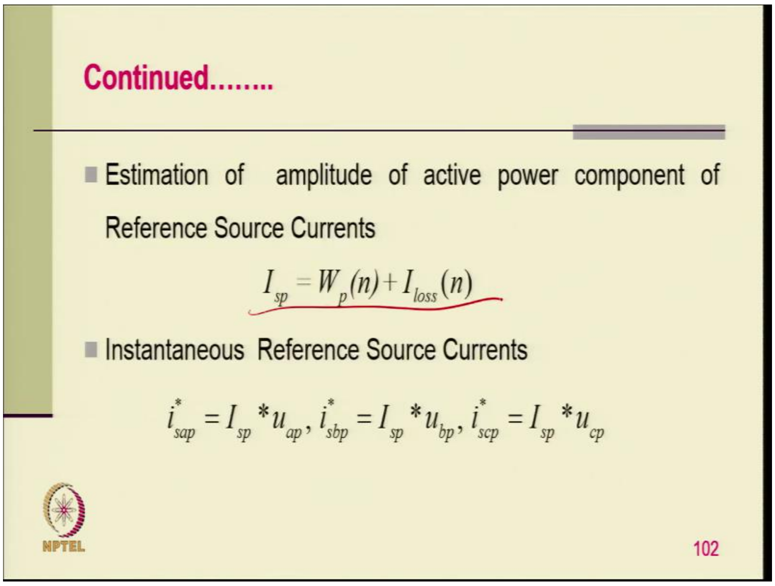
(Refer Slide Time: 34:57)



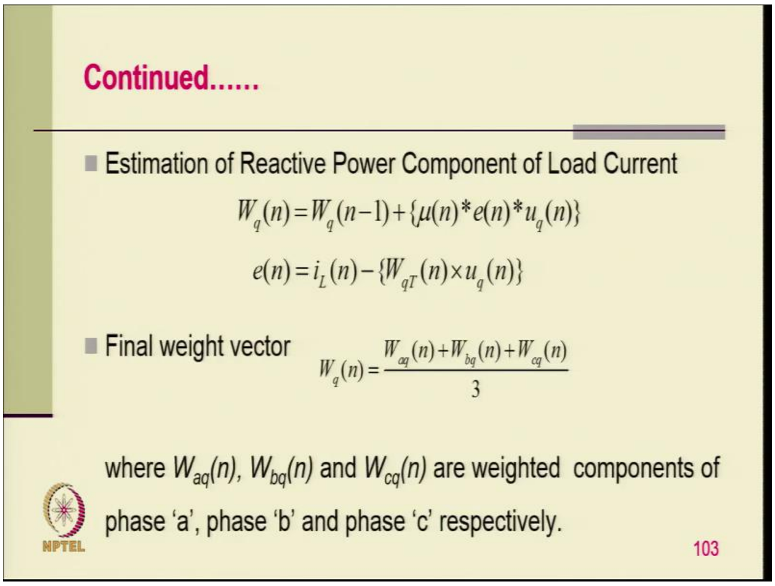
(Refer Slide Time: 35:11)



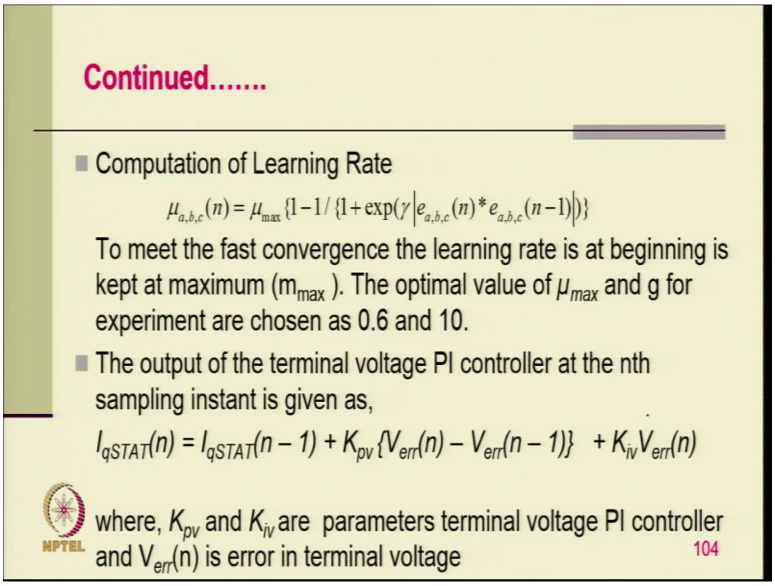
(Refer Slide Time: 35:23)



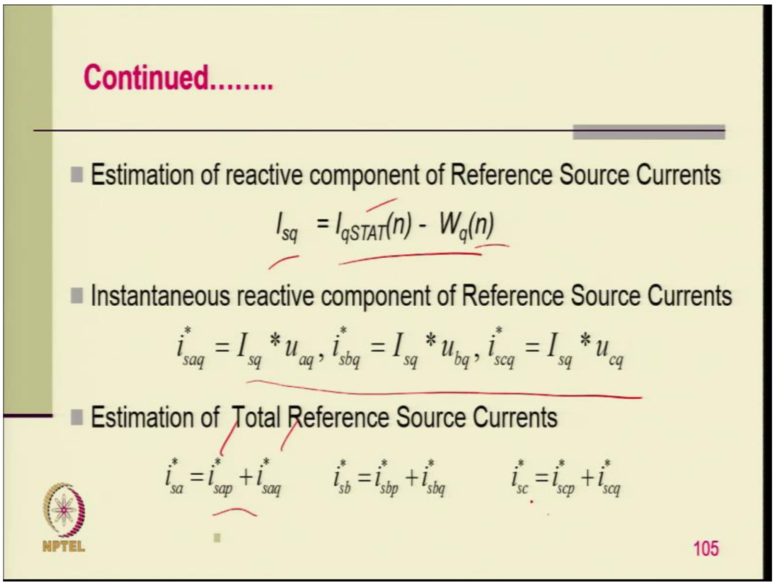
(Refer Slide Time: 35:31)



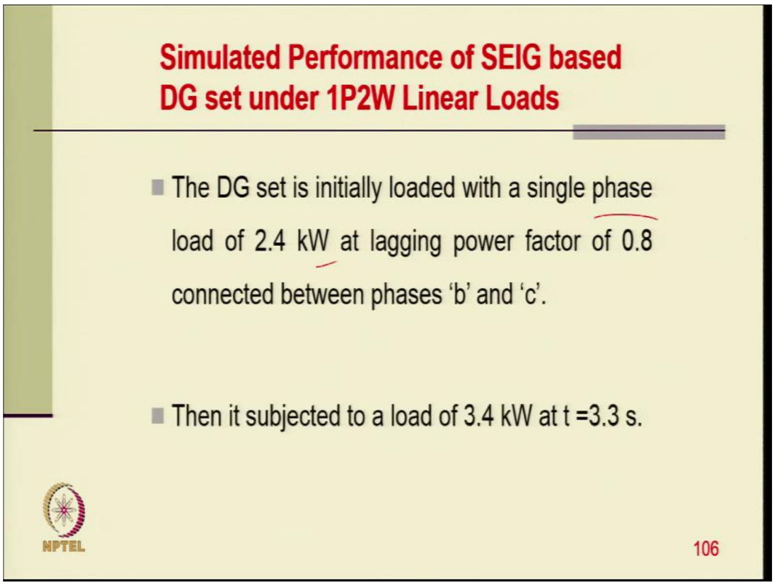
(Refer Slide Time: 35:37)



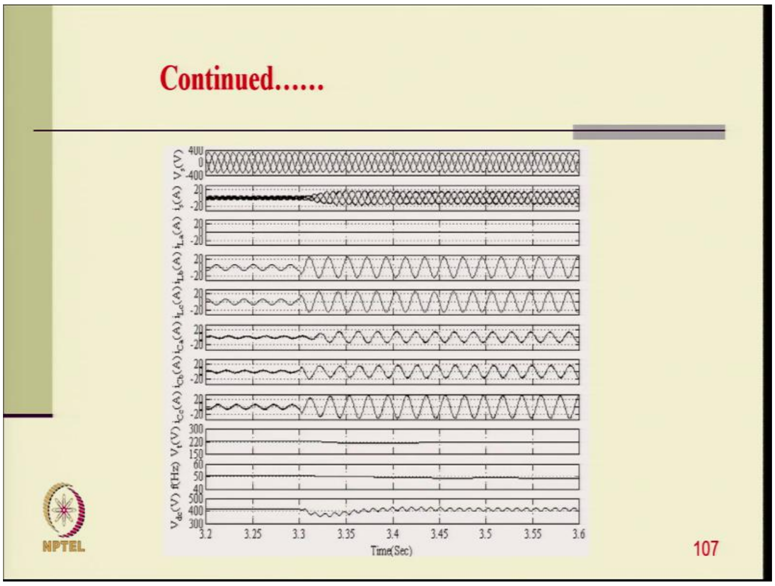
(Refer Slide Time: 35:44)



(Refer Slide Time: 36:12)



(Refer Slide Time: 36:30)



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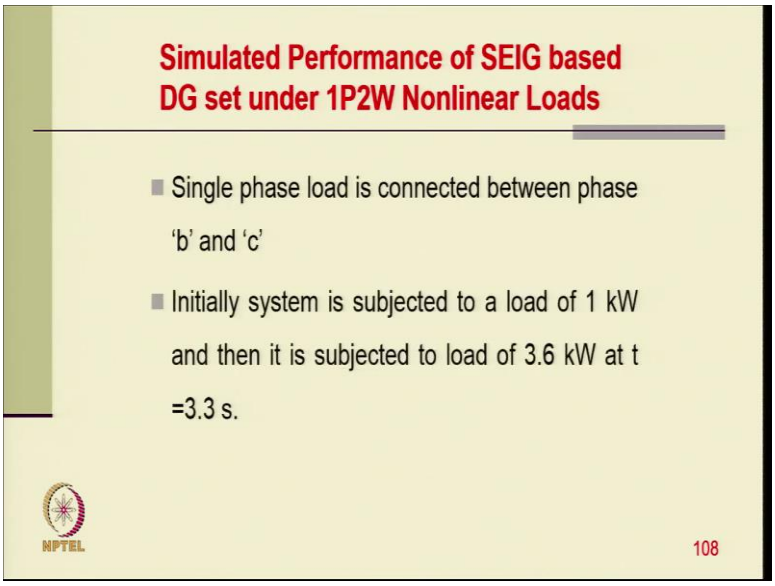
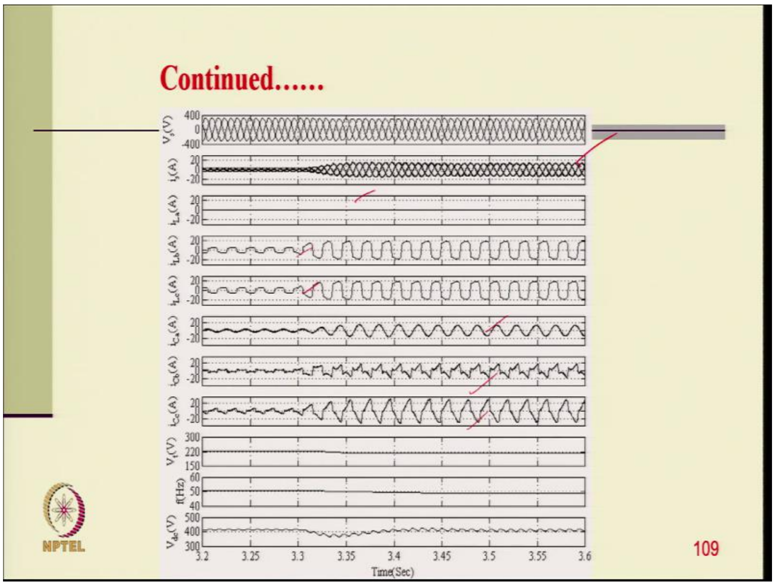
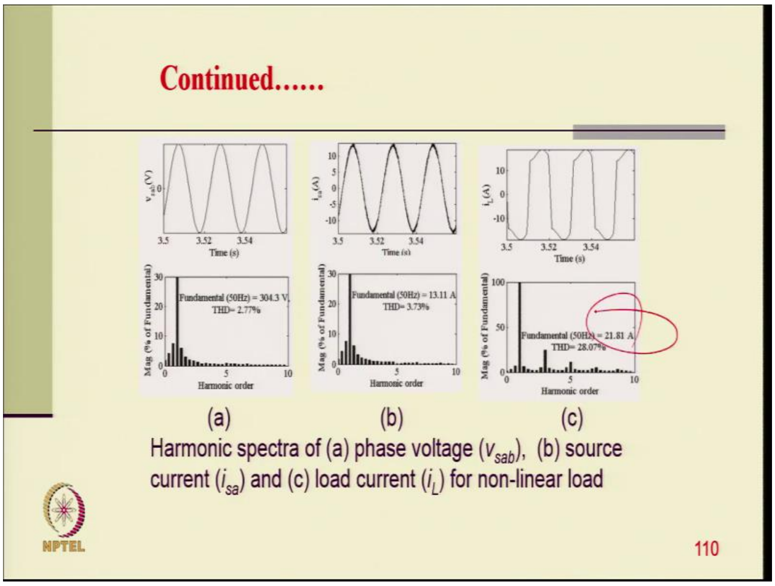


(Refer Slide Time: 36:49)

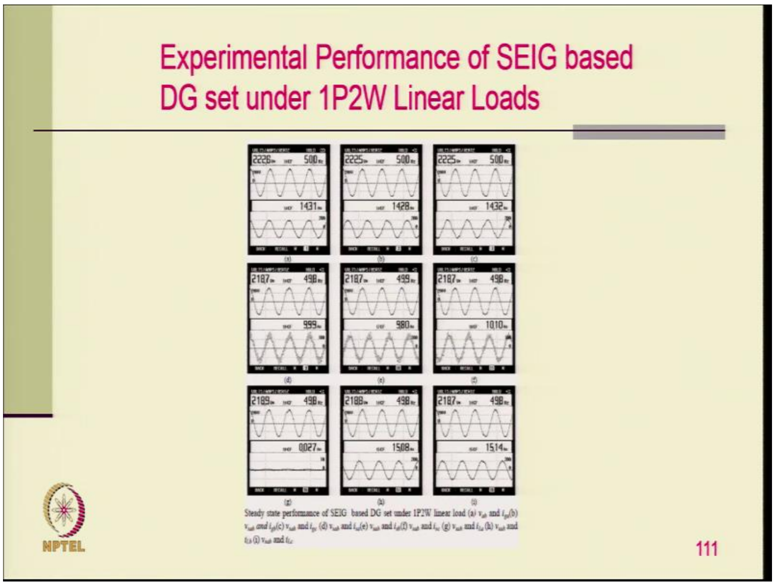


(Refer Slide Time: 37:14)

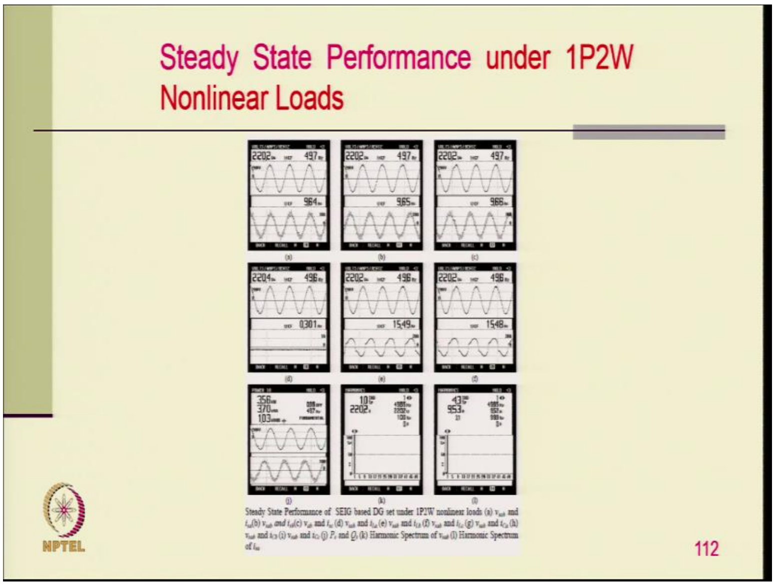


And here, the THD of the load is typically of 28%, but the THD of current generator current is 3.73 % and you can call it that THD voltage of only 2.77 %.

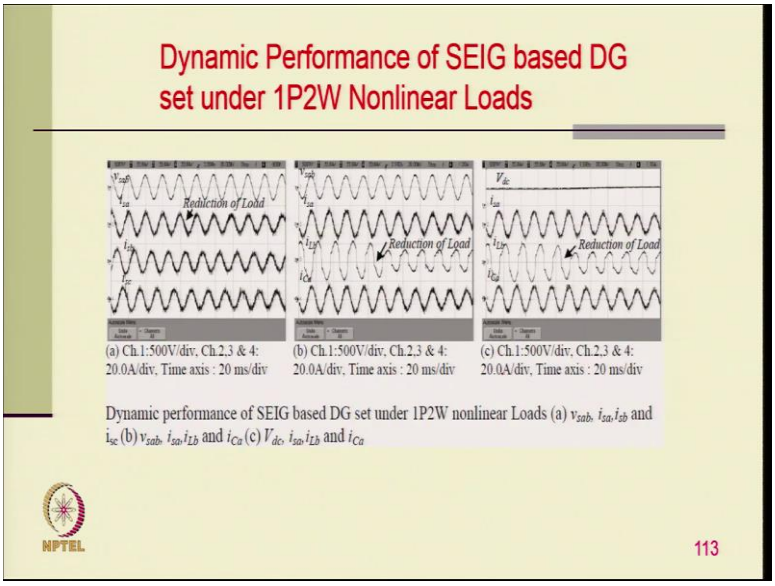
(Refer Slide Time: 37:25)



(Refer Slide Time: 37:35)

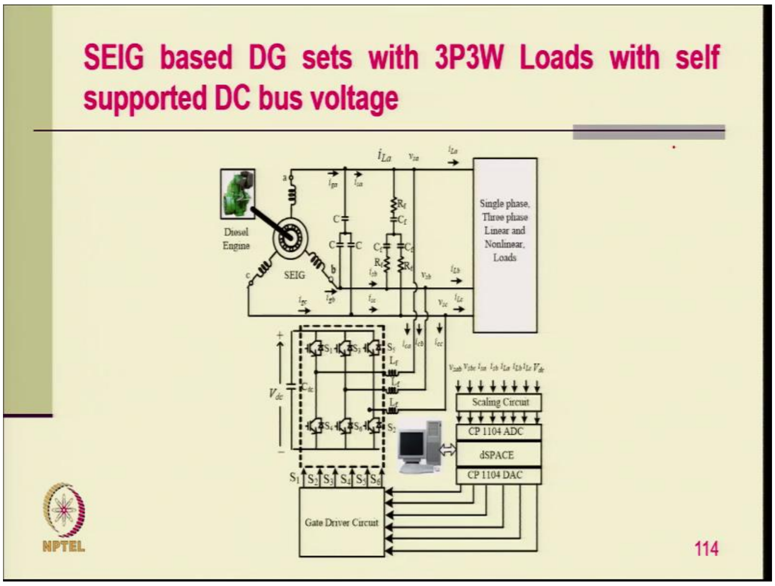


(Refer Slide Time: 37:55)

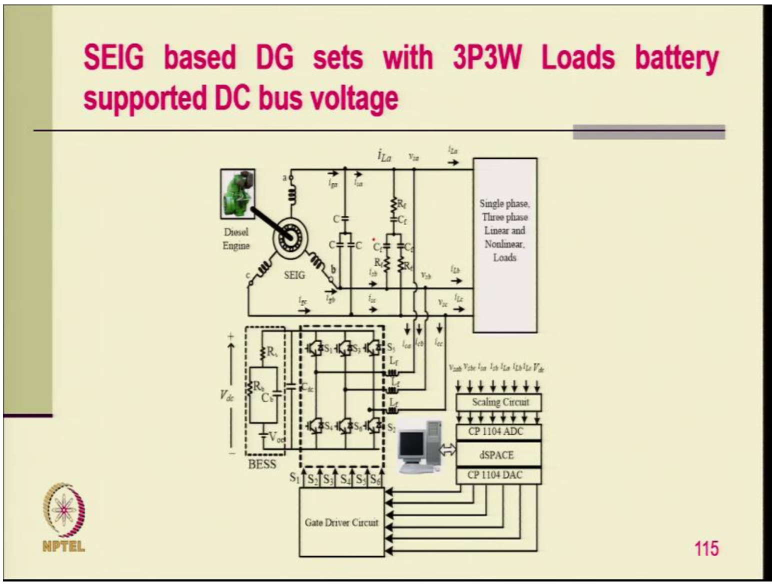


These are the dynamic performance of SEIG based DG set under 1P2W nonlinear loads.

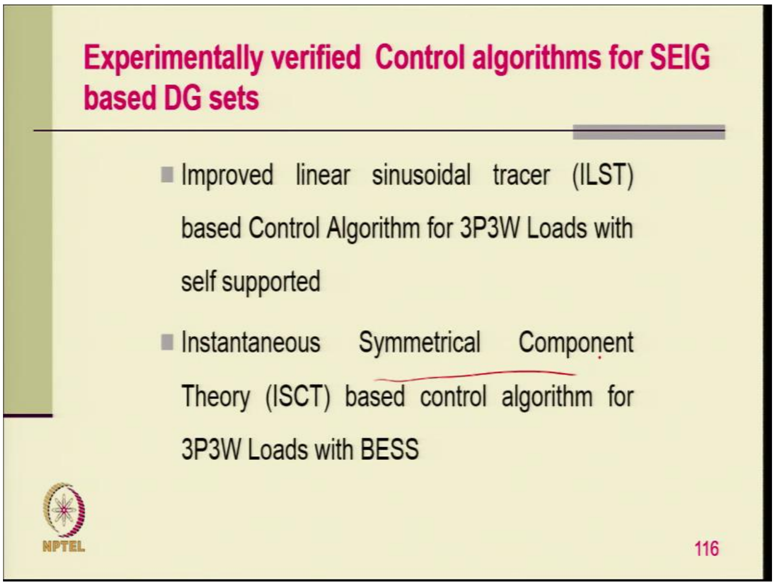
(Refer Slide Time: 38:05)



(Refer Slide Time: 38:16)

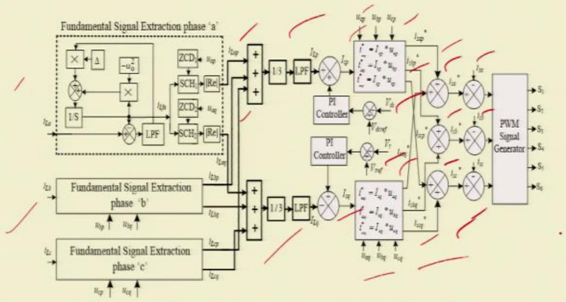


(Refer Slide Time: 38:21)



(Refer Slide Time: 38:31)

ILST based Control Algorithm for 3P3W Loads with self supported DC bus voltage



(Refer Slide Time: 39:07)

Continued……

- Estimation of Instantaneous Phase Voltages

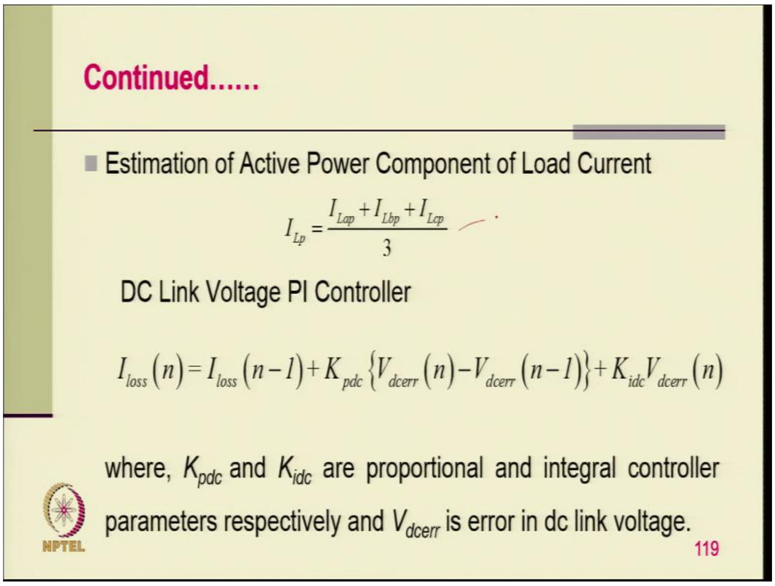
$$\begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & 1 \\ -1 & 1 \\ -1 & -2 \end{bmatrix}\begin{bmatrix} v_{sab} \\ v_{sbc} \end{bmatrix}$$

- The amplitude of phase voltages $V_t = \sqrt{\frac{2}{3}\left(v_{sa}^2 + v_{sb}^2 + v_{sc}^2\right)}$

- Estimation of In-Phase Unit-Templates

$$u_{ap} = v_{sa}/V_t,\ u_{bp} = v_{sb}/V_t,\ u_{cp} = v_{sc}/V_t$$

(Refer Slide Time: 39:13)



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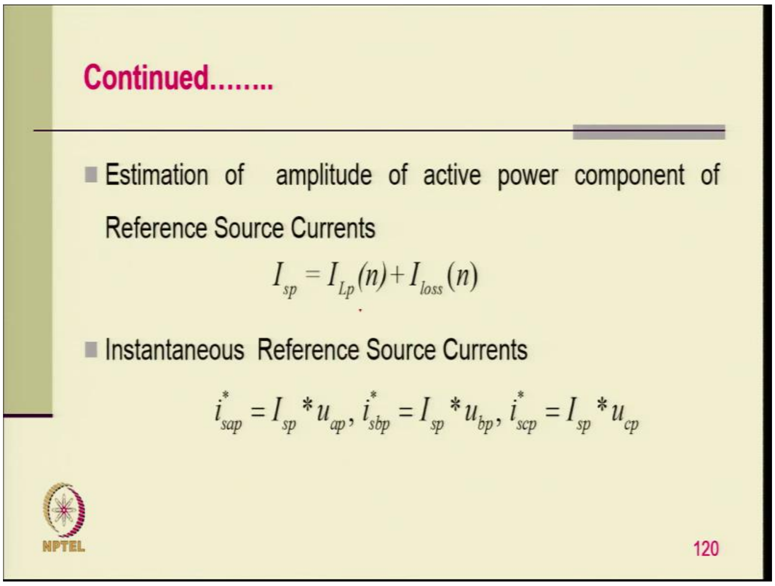

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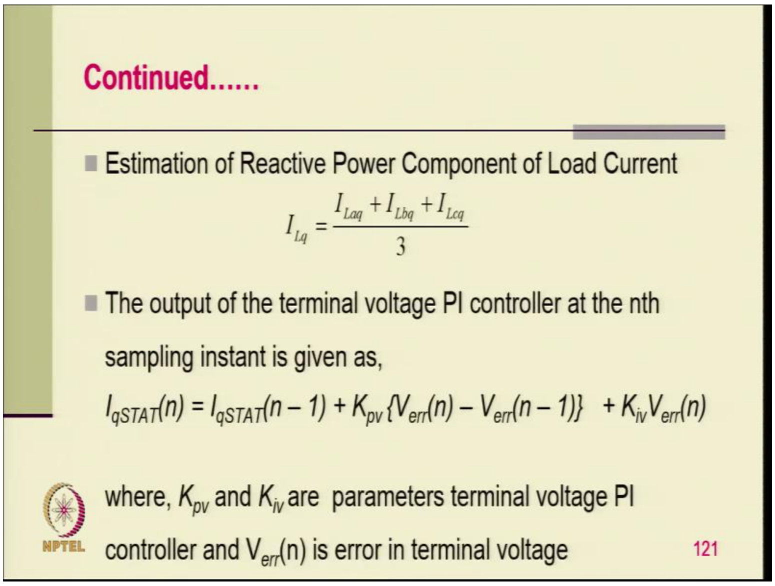

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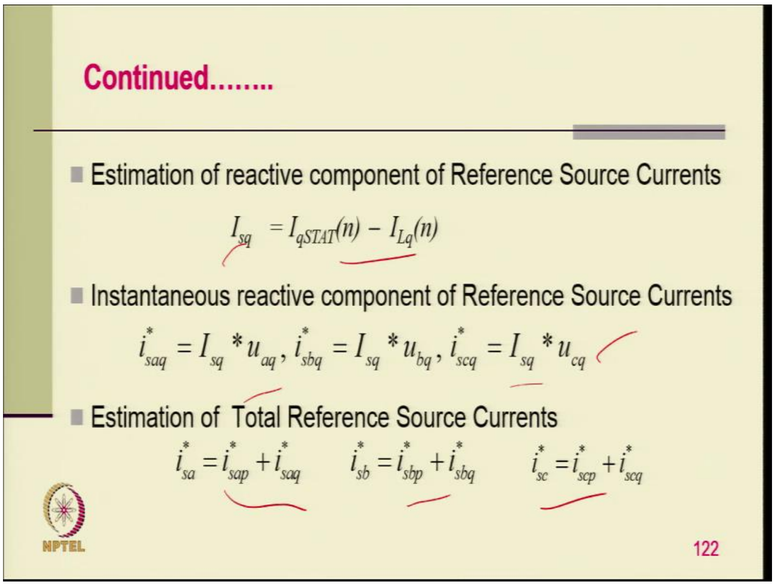
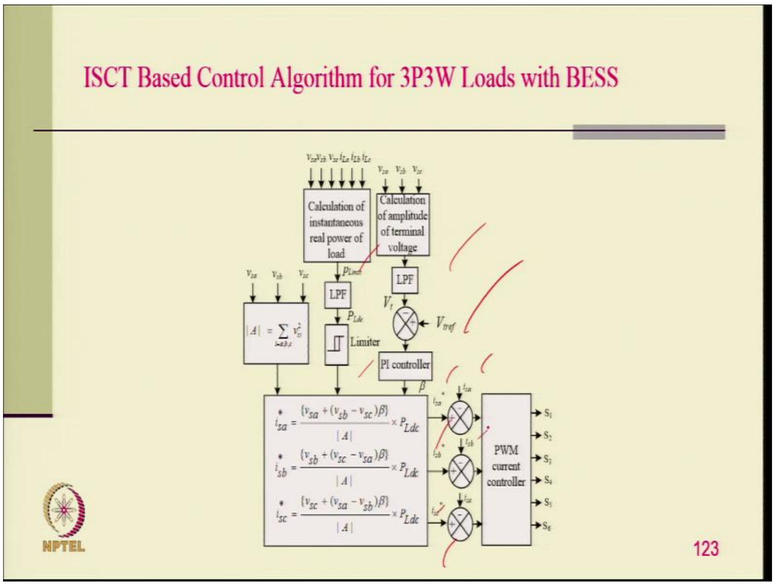


(Refer Slide Time: 40:04)



(Refer Slide Time: 40:25)

Continued......

- This algorithm uses phase voltages (v_{sa}, v_{sb}, v_{sc}), average load power(P_{Ldc}) and source power factor angle(f) for estimation of reference source currents
- Estimation of Instantaneous Phase Voltages

$$\begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & 1 \\ -1 & 1 \\ -1 & -2 \end{bmatrix}\begin{bmatrix} v_{sab} \\ v_{sbc} \end{bmatrix}$$

- The amplitude of phase voltages $V_t = \sqrt{\frac{2}{3}\left(v_{sa}^2 + v_{sb}^2 + v_{sc}^2\right)}$

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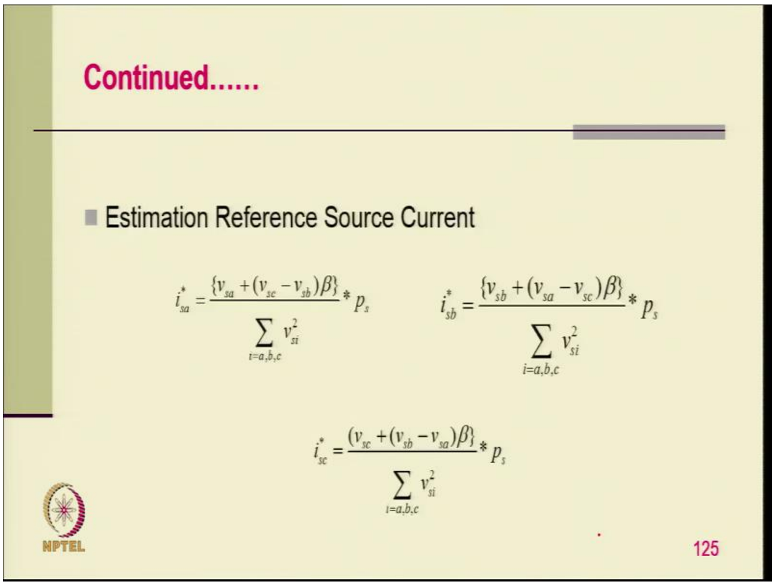
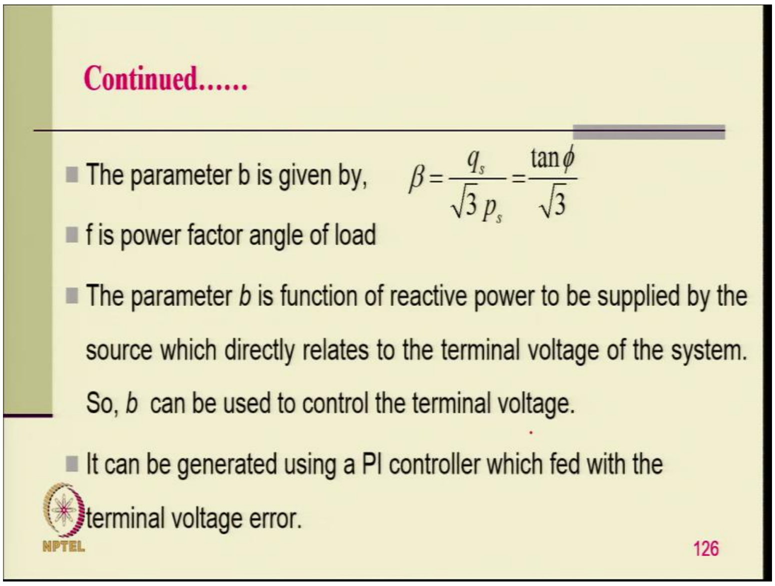
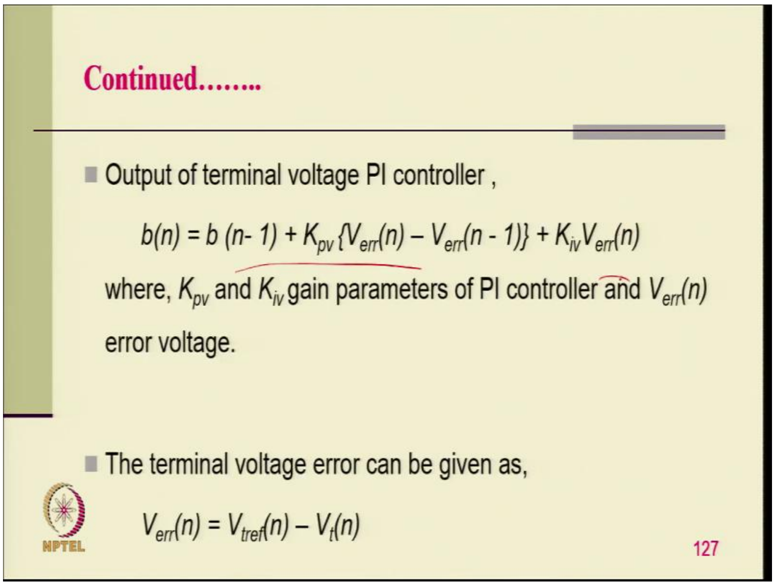
(Refer Slide Time: 40:32)



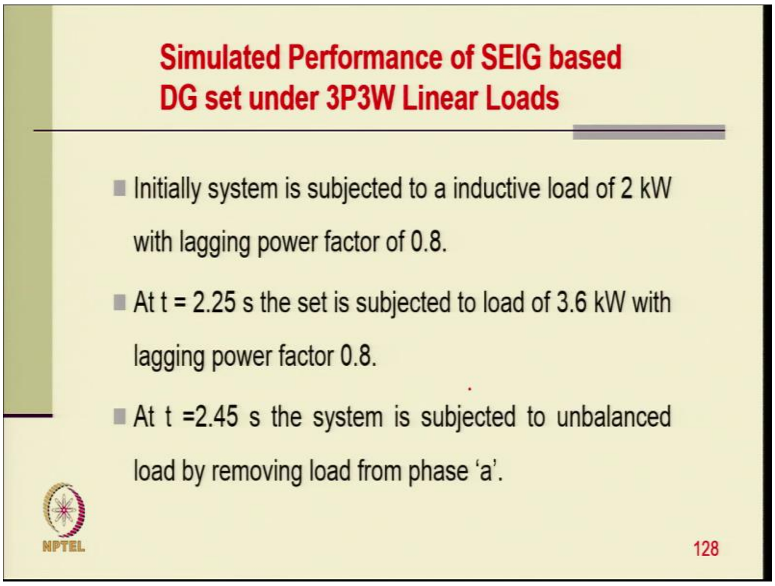
(Refer Slide Time: 40:37)



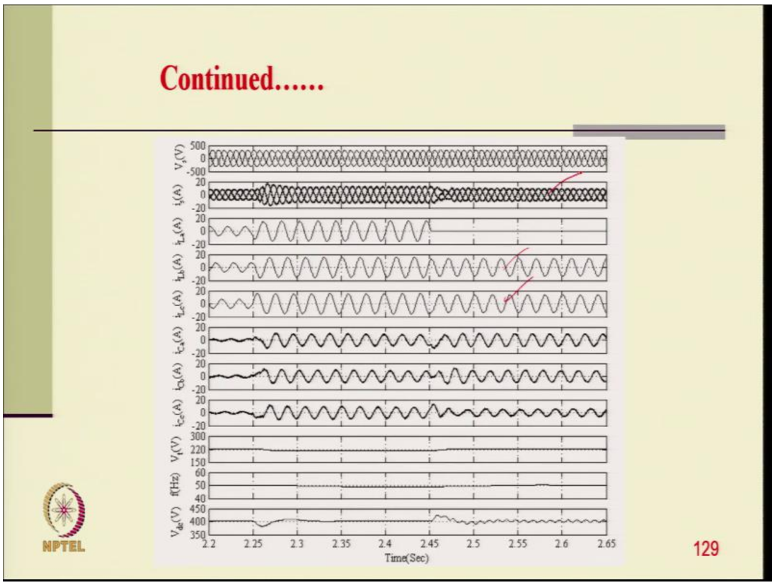
(Refer Slide Time: 40:44)



(Refer Slide Time: 40:52)

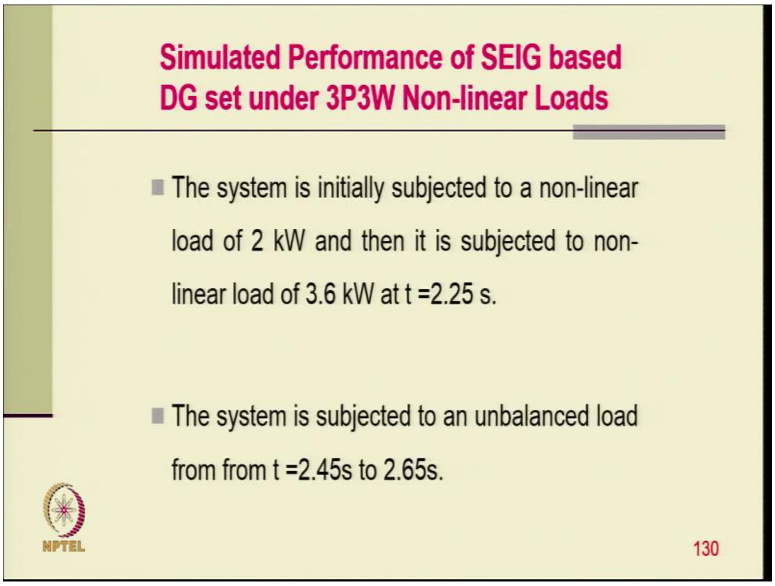


(Refer Slide Time: 40:55)

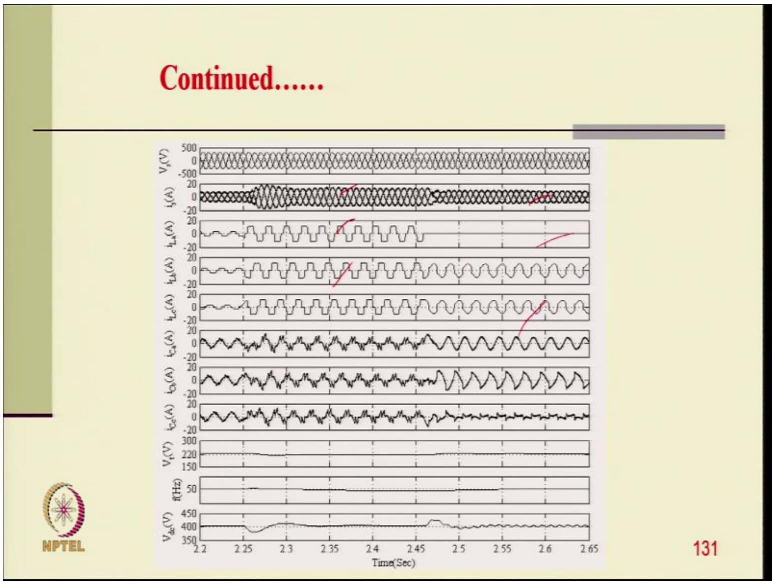


These are the simulated performance of the SEIG based DG set under 3P3W linear loads.

(Refer Slide Time: 41:00)

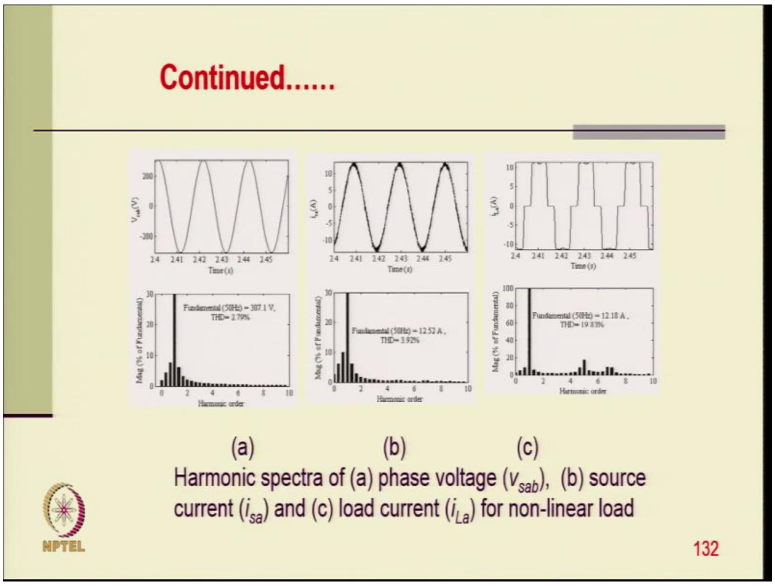


(Refer Slide Time: 41:01)



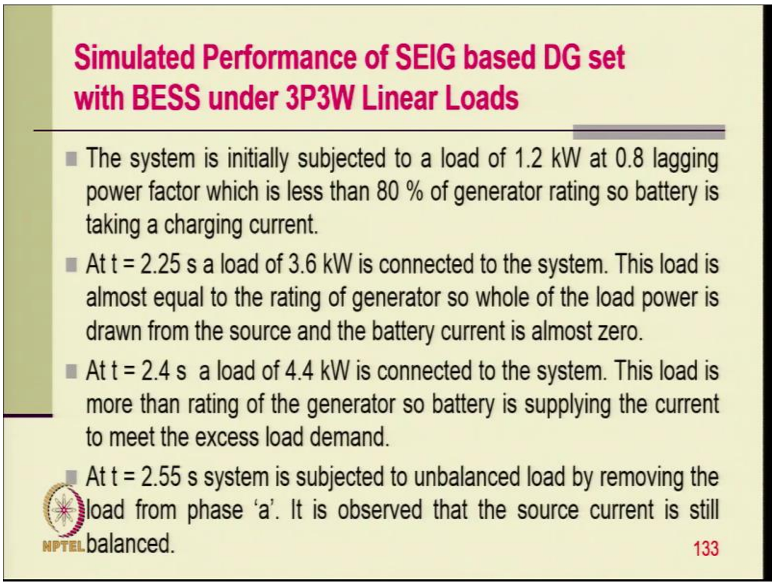
These are the simulated performance of the SEIG based DG set under 3P3W non-linear loads.

(Refer Slide Time: 41:12)

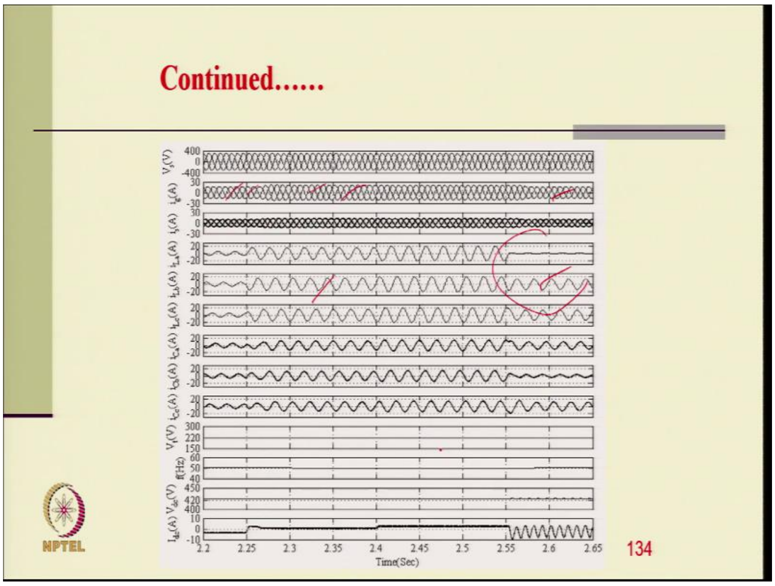


Here, we have a THD of the load; typically order of 19%, but the current THD in generator is only 3.92 % where the voltage THD is only 2.79 %.

(Refer Slide Time: 41:28)

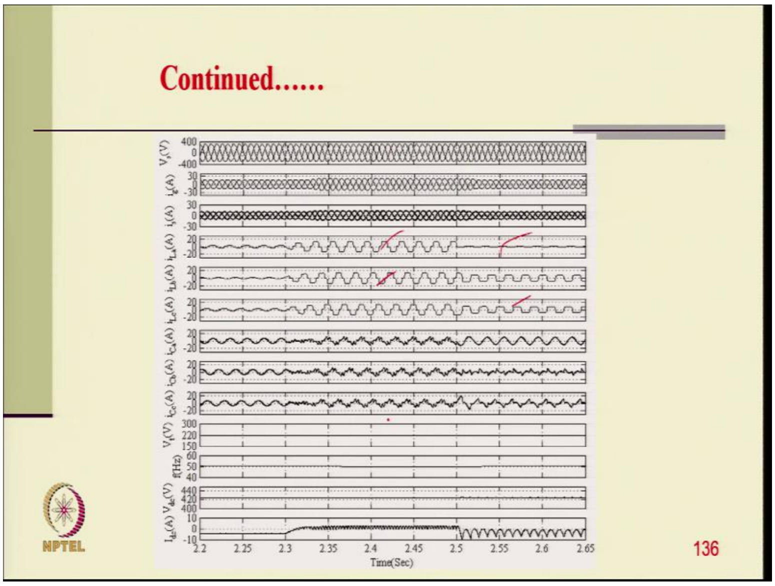


(Refer Slide Time: 41:31)

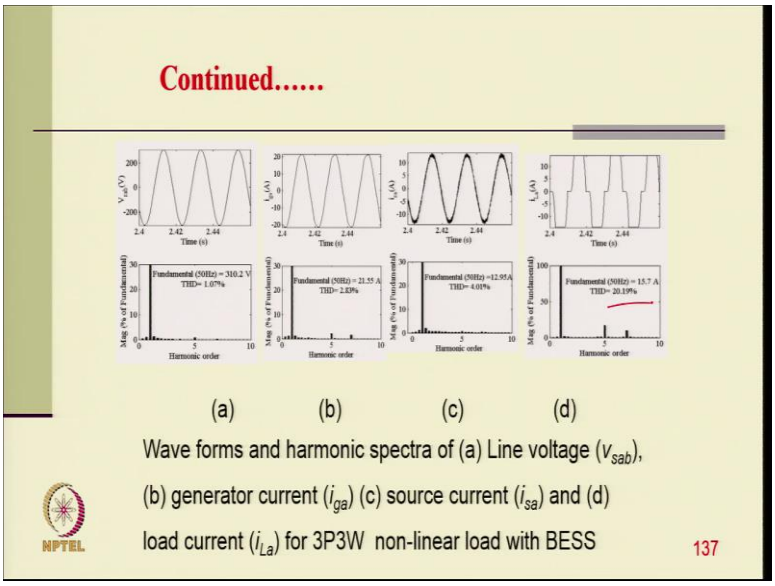


These are the simulated performance of the SEIG based DG set with BESS under 3P3W linear loads.

(Refer Slide Time: 41:58)

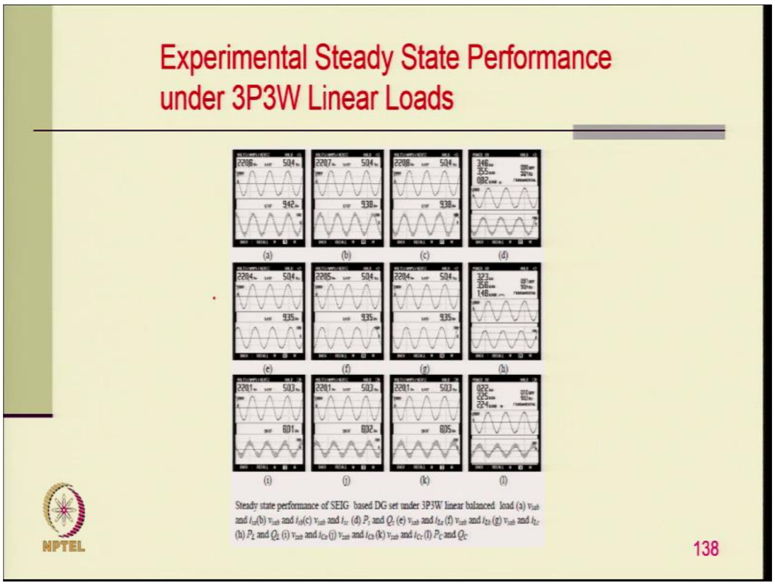


(Refer Slide Time: 42:11)



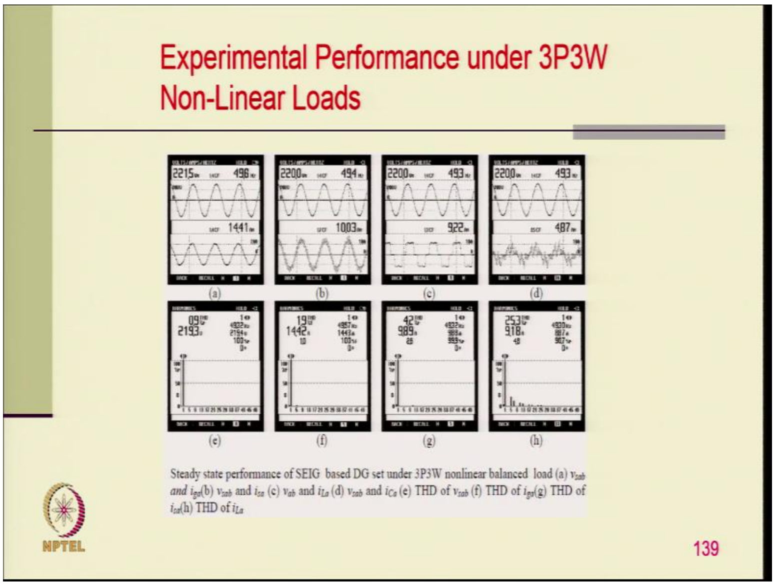
Here, we have the THD of the load current, 20%, whereas, the THD of generator current is 4 % where voltage THD is only 1%.

(Refer Slide Time: 42:22)



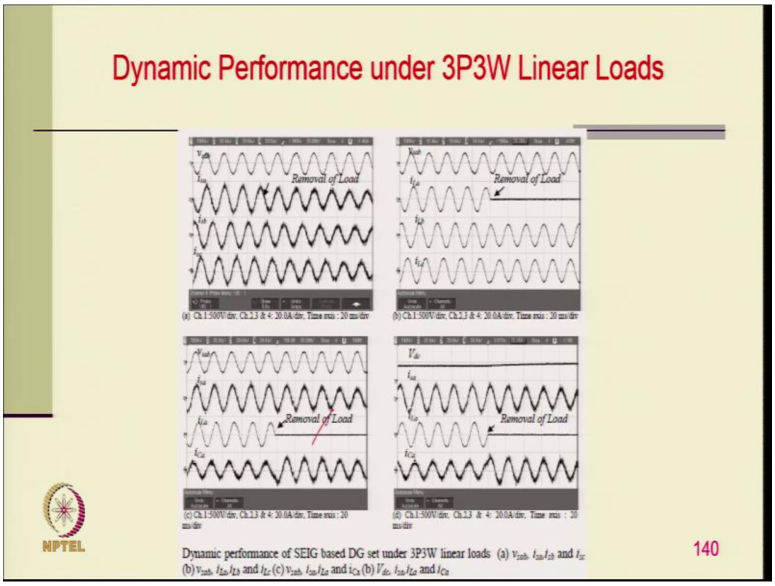
These are the experimental steady state performance under 3P3W linear loads.

(Refer Slide Time: 42:34)



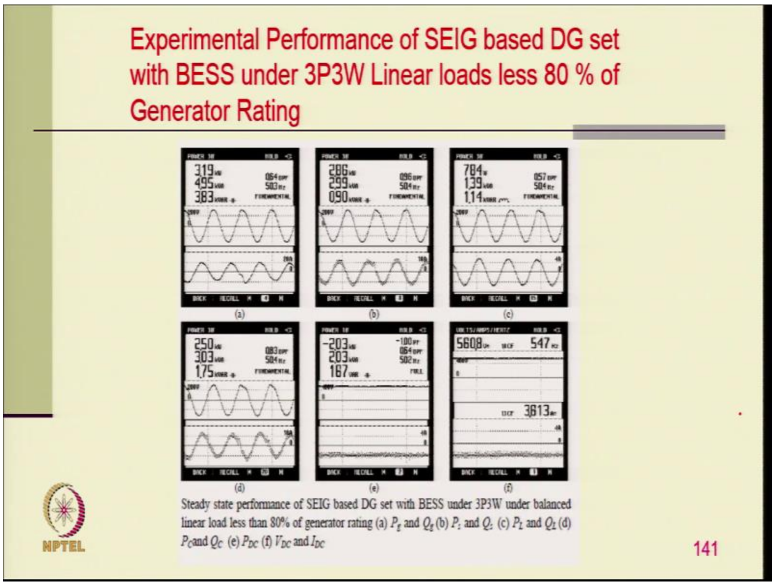
These are the experimental steady state performance under 3P3W non-linear loads.

(Refer Slide Time: 42:56)

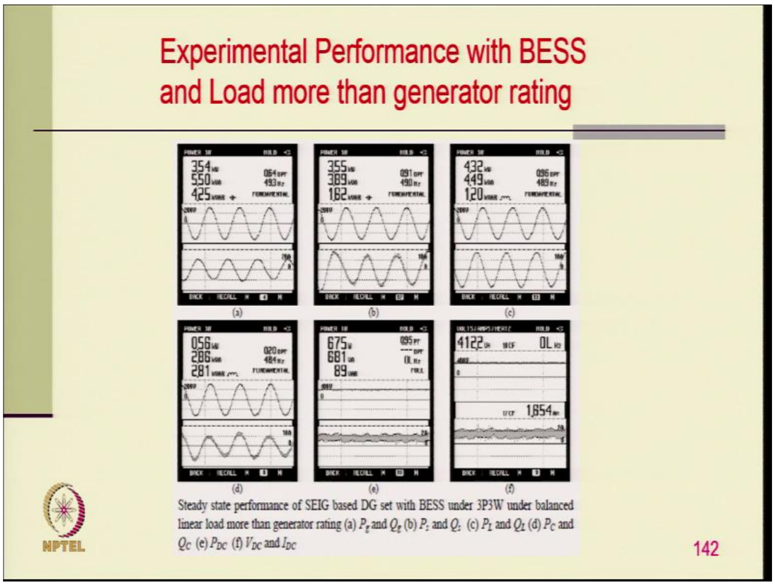


These are the experimental dynamic performance under 3P3W linear loads.

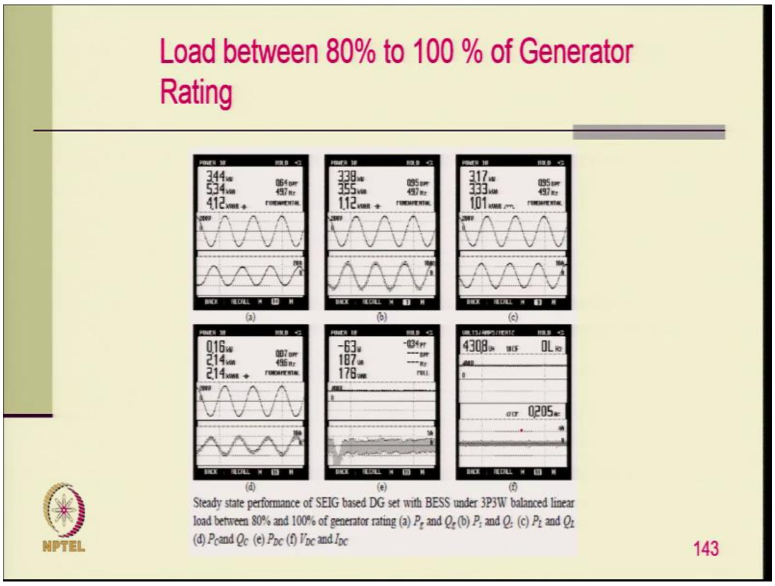
(Refer Slide Time: 43:06)



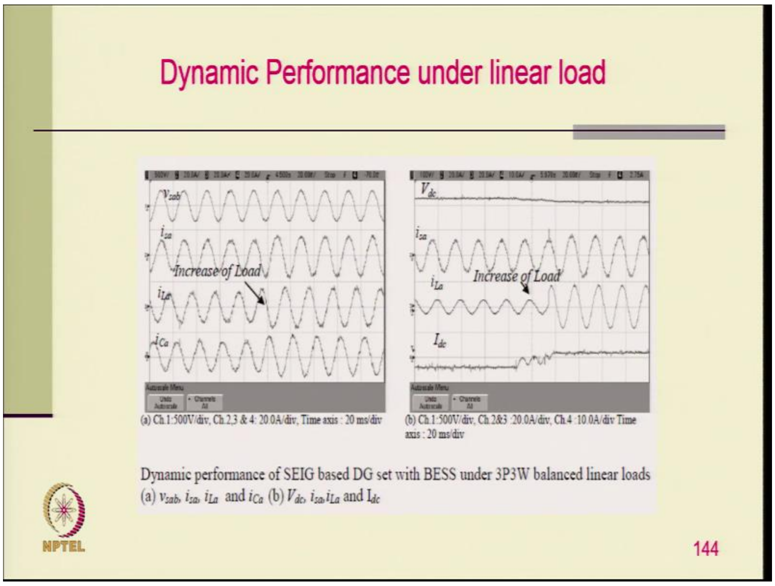
(Refer Slide Time: 43:15)



(Refer Slide Time: 43:17)

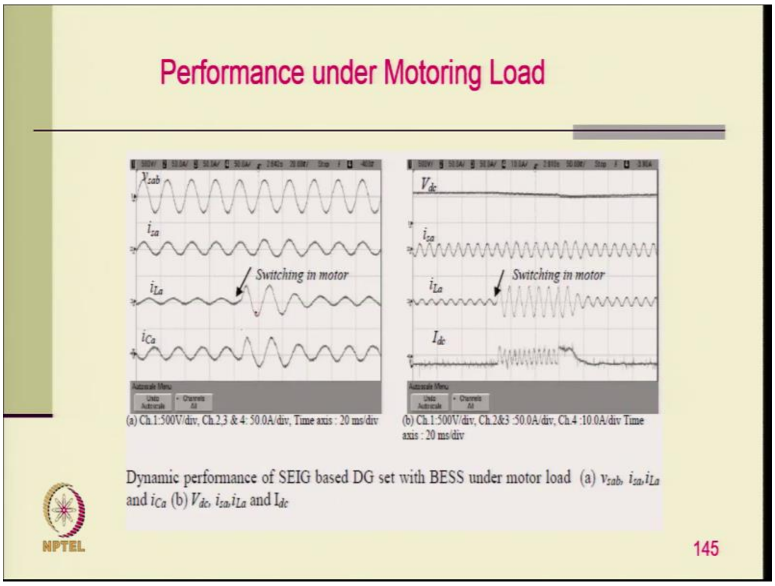


(Refer Slide Time: 43:20)



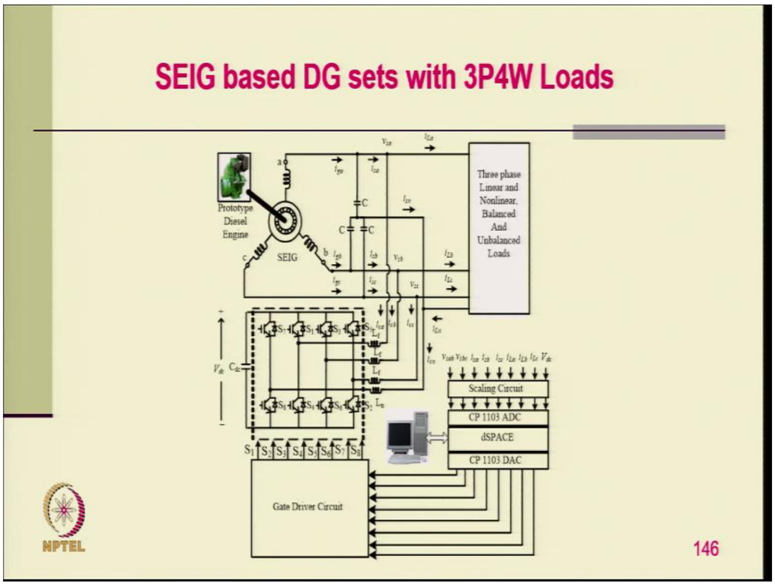
These are the experimental dynamic performance under linear loads.

(Refer Slide Time: 43:28)



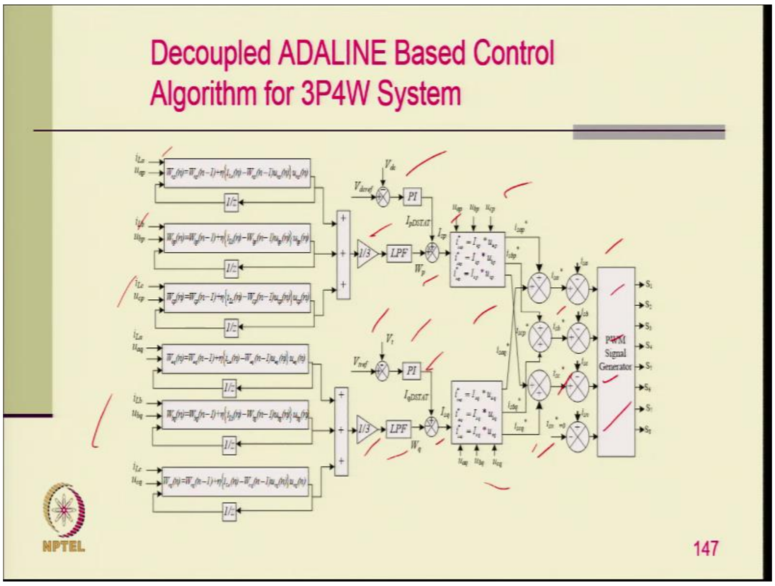
These are the experimental performance under motoring load.

(Refer Slide Time: 43:51)



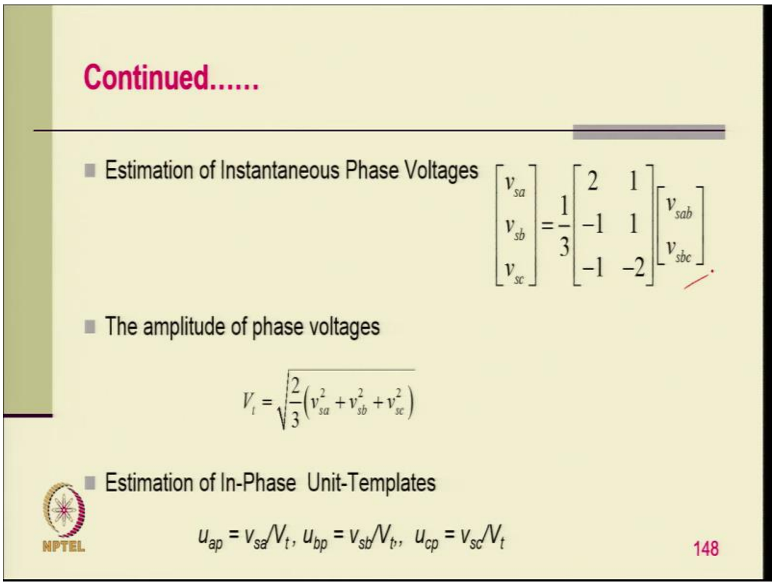
This is the circuit configuration of SEIG Based DG sets with 3P4W loads.

(Refer Slide Time: 44:13)

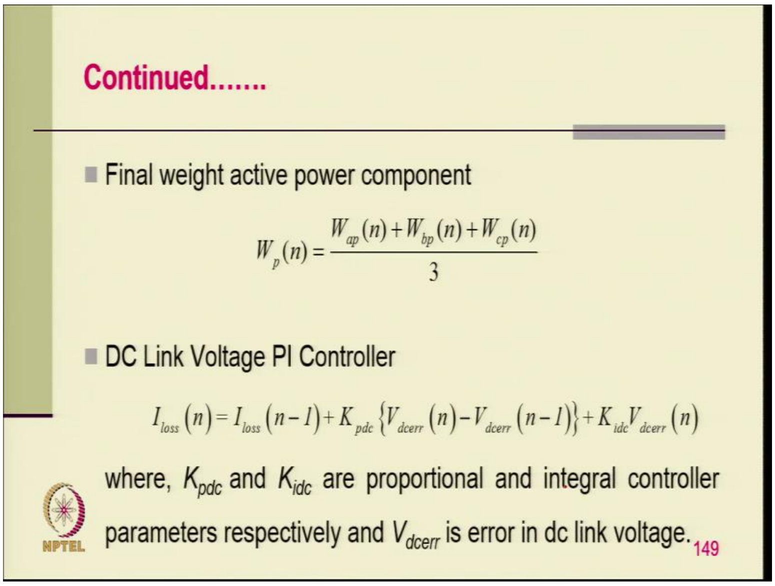


This is control algorithms applied for the control of the DG sets.

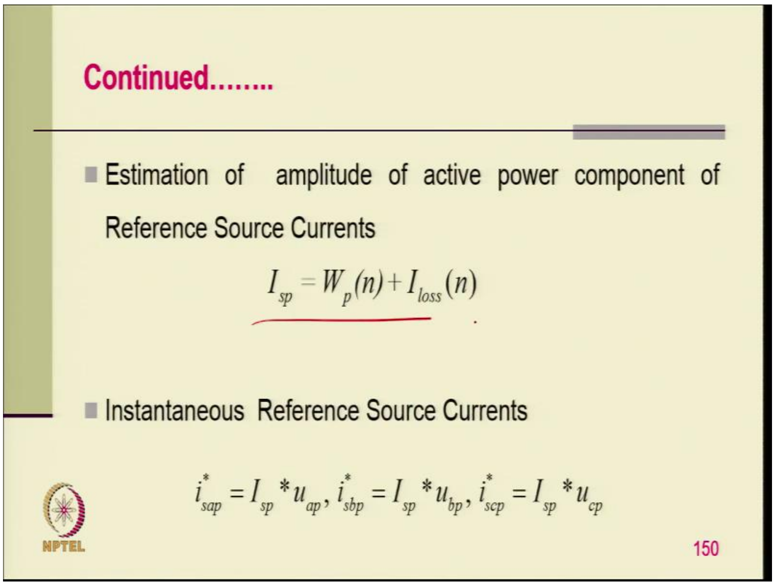
(Refer Slide Time: 45:07)



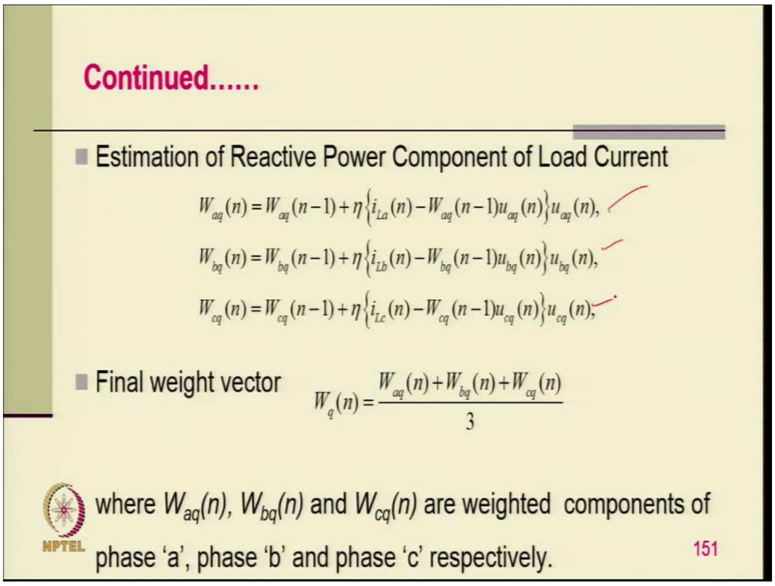
(Refer Slide Time: 45:15)



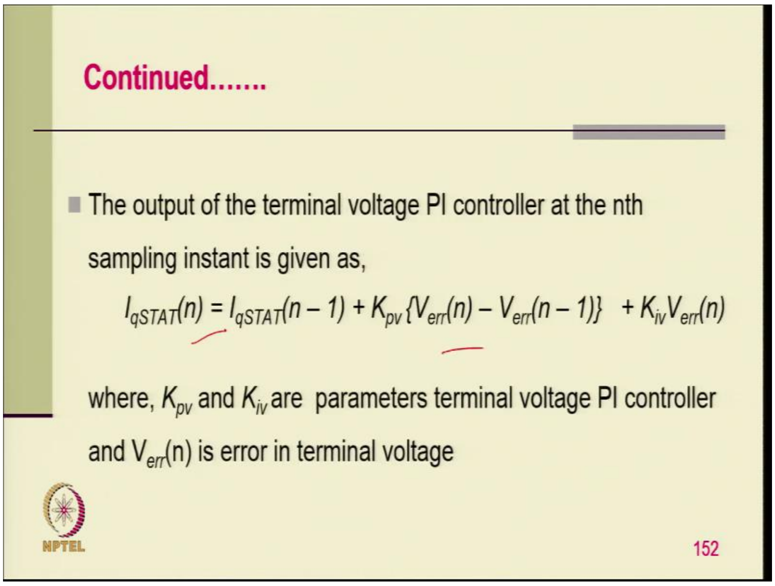
(Refer Slide Time: 45:27)



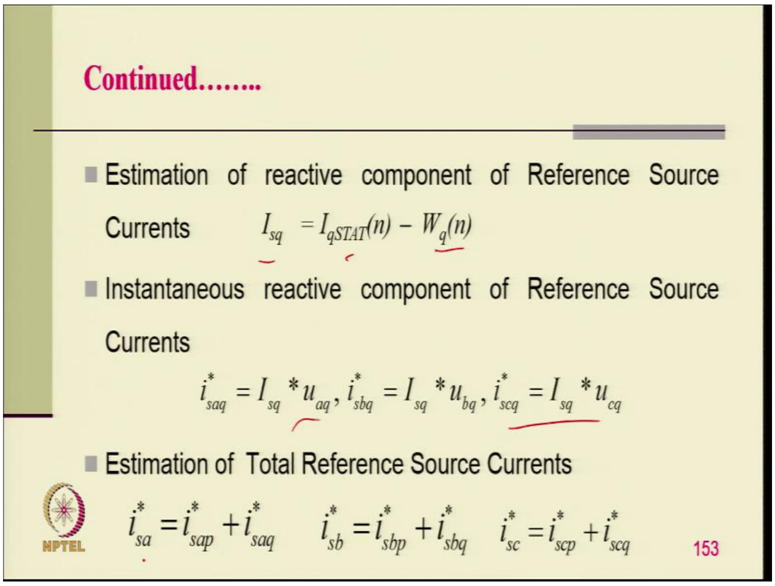
(Refer Slide Time: 45:35)



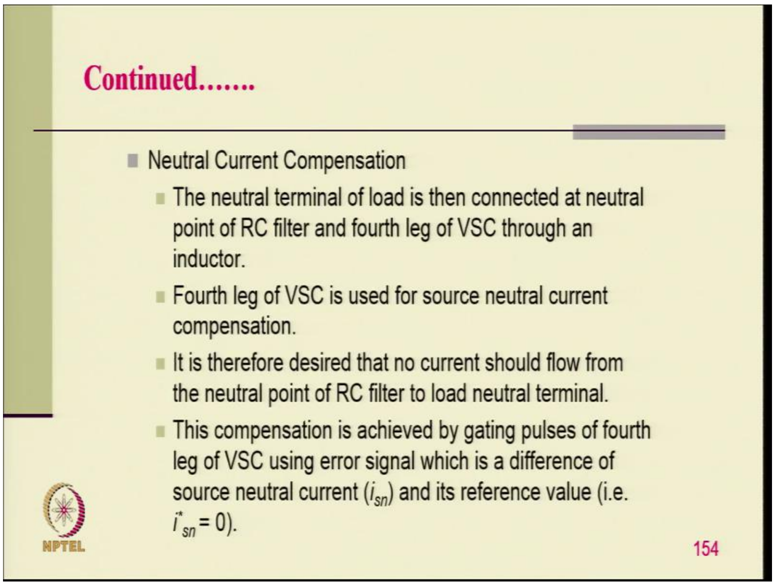
(Refer Slide Time: 45:42)



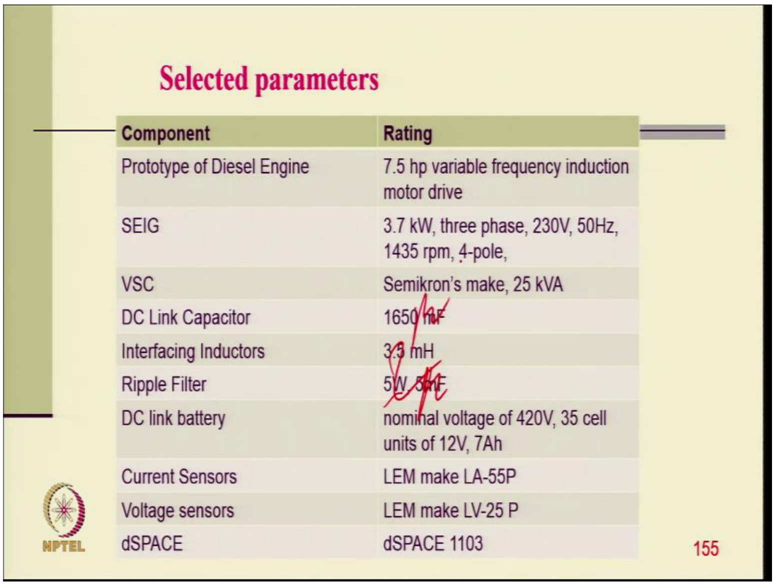
(Refer Slide Time: 45:50)



(Refer Slide Time: 46:05)

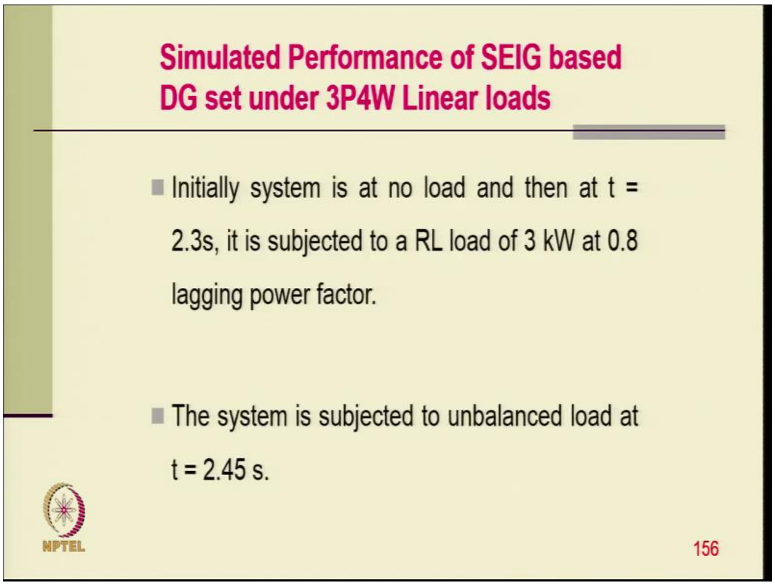


(Refer Slide Time: 46:15)

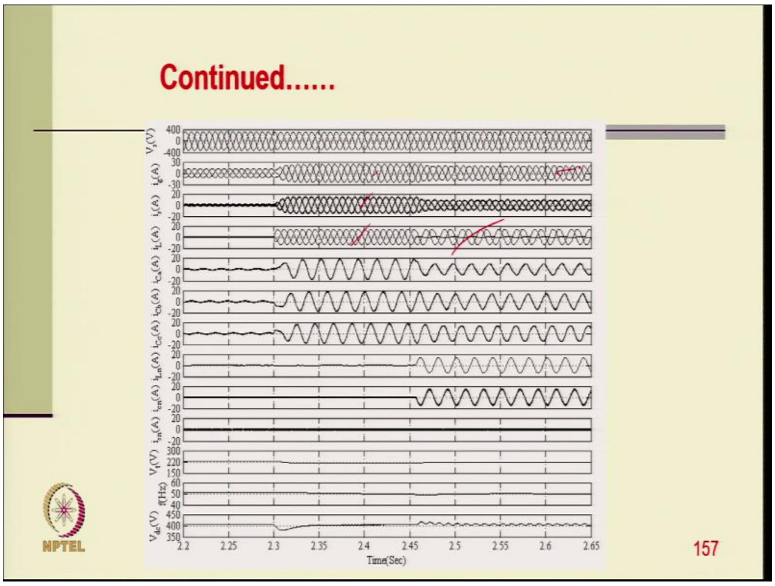


Component	Rating
Prototype of Diesel Engine	7.5 hp variable frequency induction motor drive
SEIG	3.7 kW, three phase, 230V, 50Hz, 1435 rpm, 4-pole,
VSC	Semikron's make, 25 kVA
DC Link Capacitor	1650 mF
Interfacing Inductors	3.5 mH
Ripple Filter	5W, 5mF
DC link battery	nominal voltage of 420V, 35 cell units of 12V, 7Ah
Current Sensors	LEM make LA-55P
Voltage sensors	LEM make LV-25 P
dSPACE	dSPACE 1103

(Refer Slide Time: 46:21)

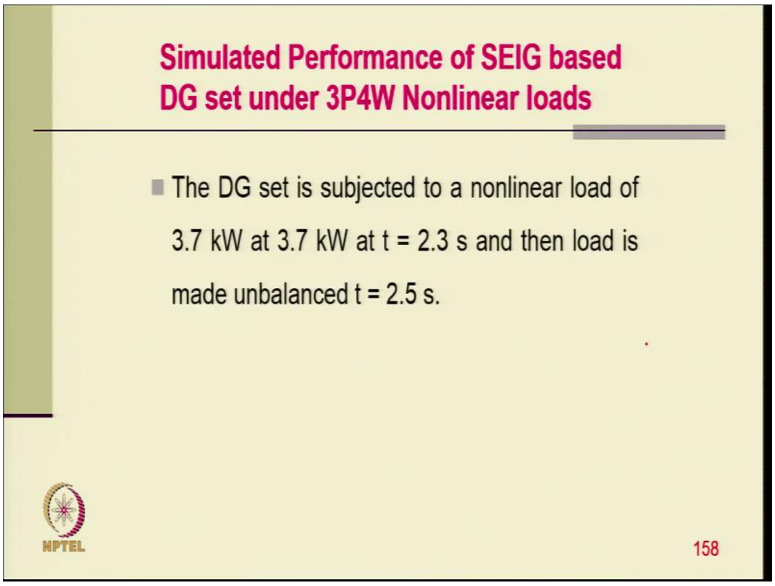


(Refer Slide Time: 46:25)

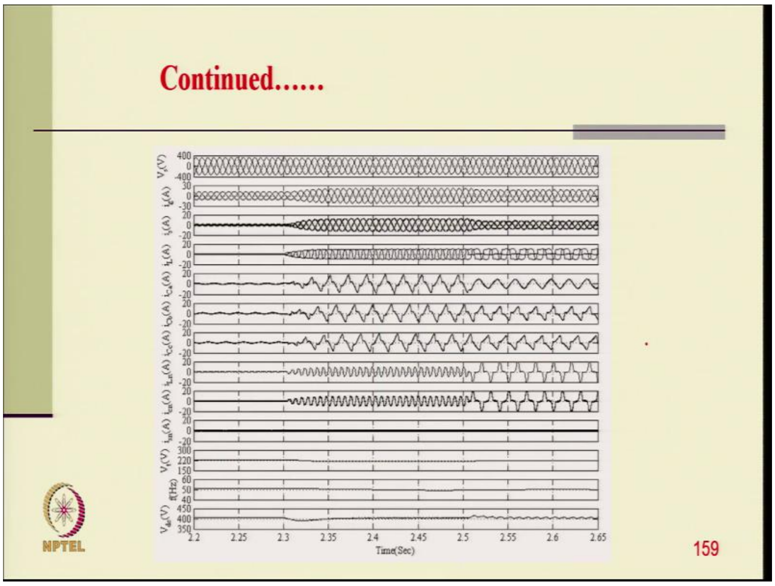


These are the simulated performance of SEIG based DG set under 3W4P linear loads.

(Refer Slide Time: 46:34)

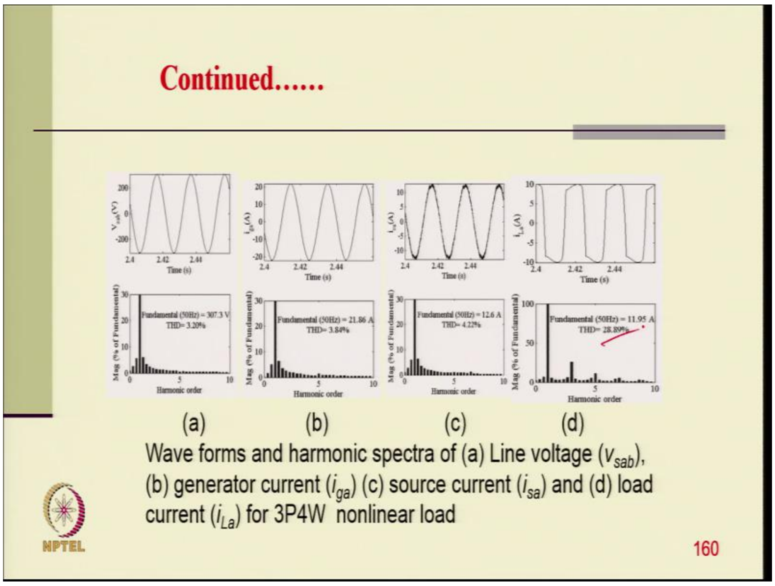


(Refer Slide Time: 46:35)



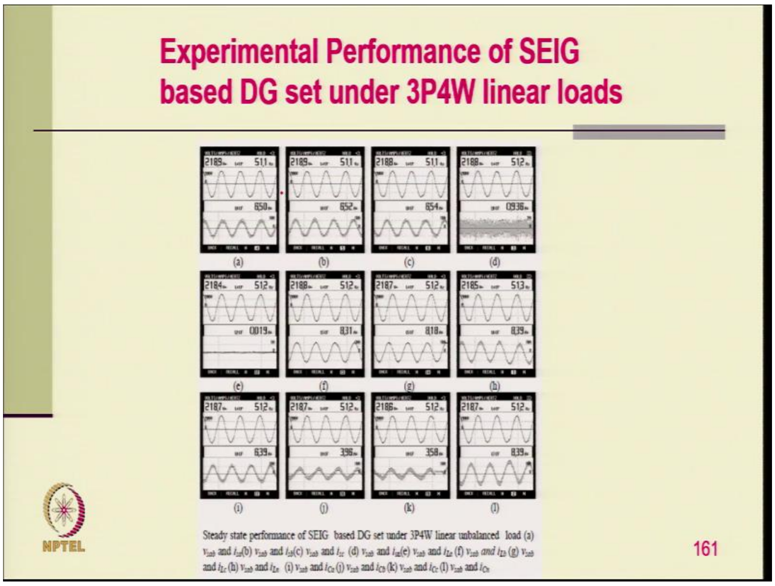
These are the simulated performance of SEIG based DG set under 3W4P non-linear loads.

(Refer Slide Time: 46:49)

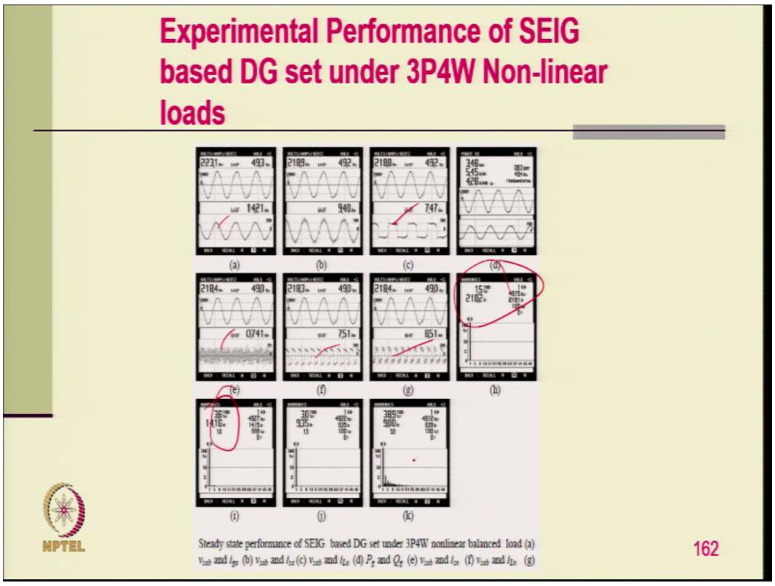


Here, the load current THD is 28.8%, whereas, the generator current THD is 3.8% and the point of common coupling voltage THD is only 3.2 %.

(Refer Slide Time: 47:02)

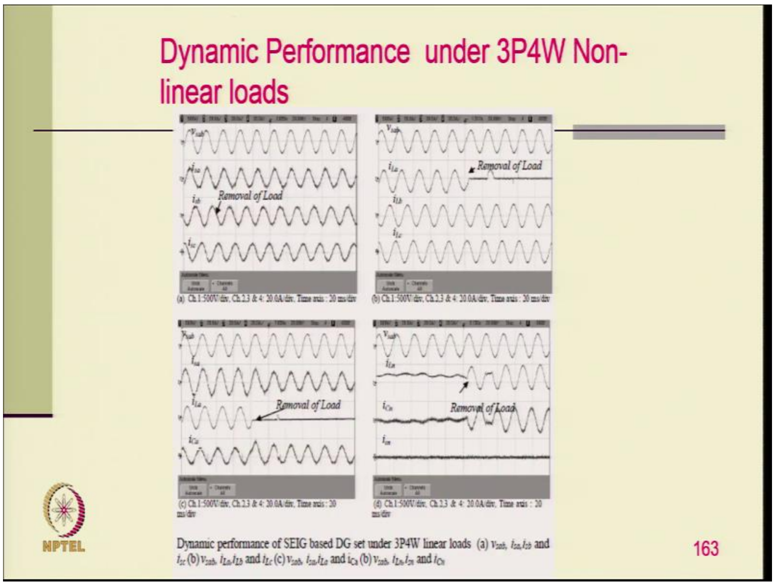


(Refer Slide Time: 47:09)



These are the experimental performance of SEIG based DG set under 3P4W non-linear loads.

(Refer Slide Time: 47:28)



These are the experimental dynamic performance under 3P4W non-linear loads.