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Performance Optimization of DG Sets of an Iron Ore Mines - A Case Study

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Abstract
In the current Energy scenario, Energy Conservation should be the prime objective of every one including Individual or Firms/Industries. This action of Conserving Energy leads to minimum Generation of Energy from different resources, as per demand and Optimum Utilisation of Generated Energy, because as we know that all this process of Generation and Utilisation Energy causes depletion of our Resources and also some sorts of Pollution. In this paper the Power Consumption detail, Saving Potential, with appropriate calculation of the Iron Ore Mines are discussed.

Keywords
Energy Conservation, Power Factor, Capacitor Bank, Diesel Consumption, DG Sets.

I. INTRODUCTION

The development of any nation depends upon its mineral resources. These minerals are extracted from earth crust through mining. In all minerals Iron is a key metal used in almost every industry and Infrastructure. The grade of the metal depends upon the techniques used in processing and refining. The machineries used for this purpose are generally heavy and power hungry which increases the energy demand and the cost of production, hence the performance of the machine in terms of efficiency, energy consumptions and loading conditions become very crucial[1][2]. This case study is carried out in four different Iron Ore Mines of JSW Steel, Odisha during June-2021 namely, Gonua Iron Ore Block, Narayaniposhi Iron Ore Block, Jajang Iron Ore Block and Nuagaon Iron Ore Block with Production Capacity of about 18 MTPA altogether[3]. All the Electrical Loads of these mines can be categorised as Light to Medium Loads which includes Official Loads like ACs, Fan, Lights etc and Lighting System of Mines, & Heavy Loads, which includes Crushers and Screening Plants. All the loads are mainly supplied by DG Sets. As out of these loads, Official Loads, similar to domestic loads, show the better Power Factor and if these loads are connected in a balanced way with appropriate rating of DG Sets, there is almost No Potential of Savings. But in case of heavy Loads which includes various motors, like in Crushers

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and Screening Plants , various factors like Protection System, Voltage Regulation, Power Factor etc, start playing a very crucial role in the Performance of Loads and its Power Consumption[4][5].

The importance of Power Factor, in term of Power Consumptions and its Savings can be understood by following expressions:

The Sending Power from Source is $S = VI$, and the Power Utilised by Loads are $P = VIcos\Phi$, here $cos\Phi$ is known as Power Factor and if it is less than 1, less Power will be Utilised by the Loads in compare to Sending Power, for Example if Power Factor is 0.8, it means Load will Utilised only 80% of Sending Power and this different become very huge in the condition of Heavy Loads. The Saving Potential can also be understood in terms of Energy like KVA-h or KW-h, by multiplying the Sending Power and Utilising Power with operational Time[6].

In this Paper the the Operational Condition i.e. Loading, Balancing, and Power Factor of only those DG Sets are discussed, which are providing Power Supply to Crushers and Screening Plants.

II. PERFORMANCE OF DG SETS

750 KVA DG Set-I:

The connected loads to this DG set are 2 Crushers of Narayaniposhi Iron Ore Block, but it's performances are studied under only one crusher load. The Readings taken from the site and displayed in tabular format in table 1 and the pictorial representation of the same for current in waveform is given in figure 1.

Table 1: Voltage, Current, Power and PF of 750 kVA DG Set-I

	L_1	**L_2**	**L_3**	**Total***
Voltage	239.7 V	239.8 V	239.7 V	
Current	372.4 A	371.1 A	374.4 A	
Power*	90.06 KVA 45.89 kW 77.50 KVAr	89.01 KVA 47.47 kW 75.29 KVAr	90.70 KVA 44.88 kW 78.81 KVAr	269.8 KVA 138.2 kW 231.6 KVAr
PF*	0.51	0.53	0.49	0.51

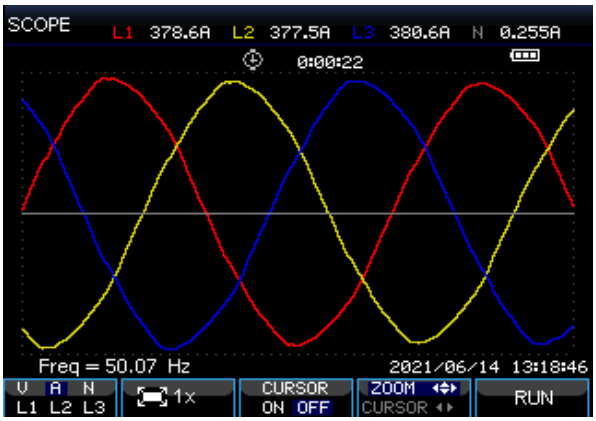

Figure 1: Current Waveform of Loads connected to 750 kVA DG Set-I

Observations:

I. As all 3-Φ loads are connected to this DG Set, loads are balanced to all it's three phases.

II. During analysing the performance, it is operating with 269.8 KVA load (36% load) but it has a total about 540 KVA load, which is 72% of it's loading capacity.

III. Operating Power Factor is 0.5 at 36% loading which needs to improve to 0.8, which is the rated Power Factor of Generator. However, when both crushers are run, the loading will be 72% and the power factor is expected to be close to 0.8, the rated pf of the DG set.

Calculation of Diesel Consumption:

As the diesel consumption of this Generator is 90 litres/hour, while operating with 276 kW (550 kVA) Load. Hence it's *Diesel consumption rate* in terms of UNIT = 276 kW×1 hr ÷90 Ltr = *3.11 kWh/ Ltr. (550kVA*× 1*hr/90 ltr = 6.11 kVAh/ltr)*

Power Factor Improvement and Calculation of Required kVAr:

When only one crusher is operated, it's pf is 0.5 but as the rated Power Factor of Generator is 0.8 so need to improve it to 0.8. By doing so, the loading capacity of Generator will improve to a considerable level. A Capacitor bank can be installed for operation when only one crusher is run.

The power consumed by one crusher is 138.2 kW

Current operating Power Factor $cos\boldsymbol{\phi}1$=0.5 i.e. $\boldsymbol{\phi}1$= 600

Desired Power Factor $cos\boldsymbol{\phi}2$=0.8 i.e. $\boldsymbol{\phi}2$= 36.860

Hence *Required kVAr*= Power Consumed in kW × (tan$\boldsymbol{\phi}$1-tan$\boldsymbol{\phi}$2) = 138× (tan 600- tan 36.860) = *135 kVAr*

Installing Capacitor banks in blocks of 25 kVAr, 125 kVAr is recommended.

Cost of kVAr (Thyristor controlled, 440V) = Rs.1350/kVAr

Hence cost of 125 kVAr capacitor bank = 1350x125 = Rs.1,68,750/-

Potential Savings calculation:

For single Crusher operation, improvement of power factor from 0.5 to 0.8 will reduce the apparent power from 276 kVA to 173 kVA.

Hence savings in diesel = (276-173)/6.11 = 16.8 litres/hr.
Considering diesel cost @Rs.93/litre, savings = Rs.1562/hour.

500 KVA DG Set-I:
This DG set is mainly connected to One unit of Crushers and 2 units of Mesto with few other loads of Narayaniposhi Iron Ore Block. The Readings taken from the above experiment is displayed in table 2 along with the pictorial view in figure 2 which shows current in waveform:

Table 2: Voltage, Current, Power and PF of 500 kVA DG Set-I

	L_1	**L_2**	**L_3**	**Total***
Voltage	240.1 V	240.1 V	240.1 V	
Current	314.4 A	312.1 A	314.3 A	
Power*	93.14 KVA 47.34 kW 80.21 KVAr	92.48 KVA 46.37 kW 80.02 KVAr	93.12 KVA 46.73 kW 80.54 KVAr	278.7 KVA 140.4 kW 240.8 KVAr
PF*	0.51	0.50	0.50	0.50

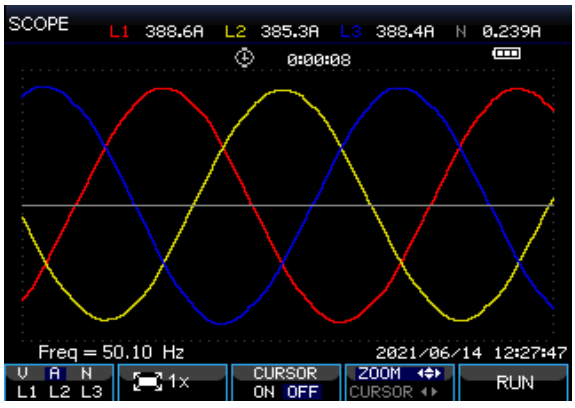

Figure 2: Current Waveform of Loads connected to 500 kVA DG Set-I

Observations:

I. As mostly 3-Φ loads are connected to this DG Set, load distribution is balanced to all its phases.

II. During analysing the performance, it is operating with 278.7 KVA load, which is about 55% of it's loading capacity.

III. Operating Power Factor is 0.50, need to improve to 0.8, which is a rated Power Factor of Generator. Calculation of Diesel Consumption: As the diesel consumption of this Generator is 45 liters/hour, while operating with 140.4kW Load. Hence it's *Diesel consumption rate* in terms of UNIT is: 140.4kW×1 hr ÷45 Ltr = *3.12 units/ Ltr (280/45 =6.2 kVAh/litre).*

Power Factor Improvement and Calculation of Required KVAr:

As the rated Power Factor of Generator is 0.8 and it is operated on 0.50 pf, so need to improve to 0.8. By doing so, the loading capacity of Generator will improve to a considerable level.

As the real power consumed by one crusher is 140.4 kW Current operating Power Factor $cos\boldsymbol{\phi}1$=0.50 i.e. $\boldsymbol{\phi}1$= 600 Desired Power Factor $cos\boldsymbol{\phi}2$=0.8 i.e. $\boldsymbol{\phi}2$= 36.860

Hence *Required kVAr*= Power Consumed in kW × (tan$\boldsymbol{\phi}$1- tan$\boldsymbol{\phi}$2) = 140.4× (tan 600- tan 36.860) = *137.91 kVAr ≈ 140 kVAr.*

Cost of kVAr (Thyristor controlled, 440V) = Rs.1350/kVAr

Hence cost of 140 kVAr capacitor bank = 1350 x 140 = Rs.1,90,000/-

Potential Savings calculation:

If the loading of this DG cannot be improved, improvement of pf from 0.5 to 0.8 will reduce the apparent power requirement from 280 kVA to 176 kVA. Hence savings in diesel = (280-176)/6.2 = 16.7 litres/hr. Considering diesel cost @Rs.93/litre, savings = Rs.1553/hour.

750 KVA DG Set-II:

The connected loads to this DG set are primarily One unit of Crusher and few other loads of Jajang Iron Ore Block. Readings taken are reflected below in table manner numbered as table 1 and the image of current in waveform shown below in figure 3:

Table 3: Voltage, Current, Power and PF of 750 kVA DG Set-II

	L_1	**L_2**	**L_3**	**Total***
Voltage	233.3 V	233.7 V	234.2 V	
Current	430.2 A	287.2 A	293.5 A	

Power*	92.36 KVA 42.71 kW 81.89 KVAr	62.21 KVA 22.31 kW 58.07 KVAr	63.78 KVA 30.75 kW 55.87 KVAr	218.3 KVA 95.77 kW 195.8 KVAr
PF*	0.46	0.36	0.48	0.44

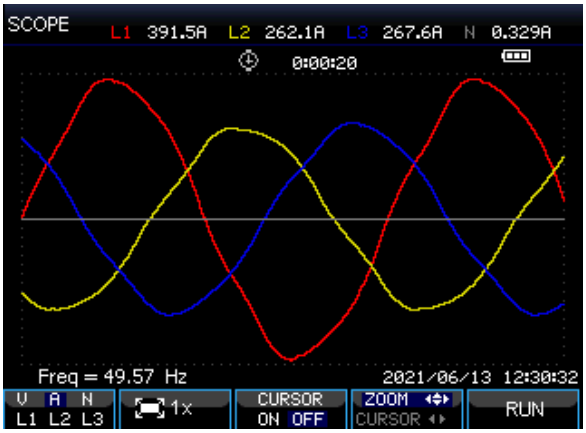

Figure 3: Current Waveform of Loads connected to 750 kVA DG Set-II

I. Both types (1-phase and 3-Phase) loads are connected to this DG set, and it found that R-phase has more load, in comparison to Y and B Phases. Need to reshuffle the loads to all its three phases.

II. During analysing the performance, it is operating with 218.3 KVA load which is 29.1% of it's loading capacity.

III. Its operating power Factor is 0.44, which is very poor, and needs to improve to 0.8, because it is a Rated operating power factor of Generator, because this condition reduces the Loading capacity of Generator and comparatively fuel Consumption increases.

Calculation of Diesel Consumption:

The diesel consumption of the DG set is 63 litres/hour operating with 95.77 kW Load. Hence it's *Diesel consumption rate* in terms of UNIT is:

= 95.77kW×1 hr ÷63 Ltr = *1.52 units/ Ltr (218/63 =3.46 kVAh/litre).*

Power Factor Improvement and Calculation of Required KVAr:

As the rated Power Factor of Generator is 0.8 and it is operated on 0.44 pf, so need to improve to 0.8. By doing so, the loading capacity of Generator will improve to a considerable level. As the real power supplied by this Generator is 95.77 kW Current operating Power Factor $cos\boldsymbol{\phi}1$=0.44 i.e. $\boldsymbol{\phi}1$= 63.890 Desired Power Factor $cos\boldsymbol{\phi}2$=0.8 i.e. $\boldsymbol{\phi}2$= 36.860

Hence *Required KVAr*= Power Consumed in kW × (tan$\boldsymbol{\phi}$1- tan$\boldsymbol{\phi}$2) = 95.77× (tan63.890- tan 36.860) = *123.60 KVAr i.e. 125 kVAr*

Cost of kVAr (Thyristor controlled, 440V) = Rs.1350/kVAr
Hence cost of 125 kVAr capacitor bank = 1350x125 = Rs.1,68,750/-
Potential Savings calculation:
Improvement of power factor from 0.44 to 0.8 will reduce the apparent power from 218 kVA to 120 kVA. Hence savings in diesel = (218-120)/3.46 = 28.3 litres/hr. Considering diesel cost @Rs.93/litre, savings = Rs.2631.9/hour.

500 KVA DG Set-II:
The connected loads to this DG set are three units of the Screening Plant of Jajang Iron Ore Block. Reading taken are:

Table 4: Voltage, Current, Power and PF of 500 kVA DG Set-II

	L_1	**L_2**	**L_3**	**Total***
Voltage	242.7 V	242.1 V	242.4 V	
Current	374.6 A	374.3 A	371.8 A	
Power*	86.87 KVA 66.71 kW 55.65 KVAr	86.56 KVA 67.16 kW 54.61 KVAr	86.07 KVA 66.38 kW 54.79 KVAr	259.5 KVA 200.3 kW 165.0 KVAr
PF*	0.77	0.78	0.77	0.77

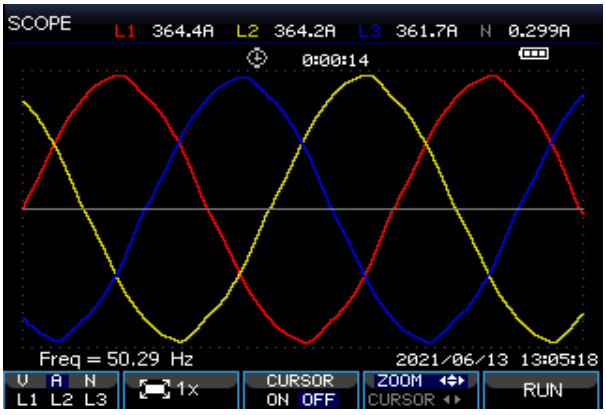

Figure 4: Current Waveform of Loads connected to 500 kVA DG Set-II

Observations:

I. As mostly 3-Φ loads are connected to this DG Set, loads are balanced to all it's three phases.
II. During analysing the performance, it is operating with 259 KVA load which is 51.8% of it's loading capacity.
III. Its operating power Factor is 0.77, which is good, because 0.8 is an operating power factor of Generator.

Calculation of Diesel Consumption:

As the diesel consumption of this Generator is 45 litres/hour, while operating with 200.3 kW Load. Hence it's *Diesel consumption rate* in terms of UNIT = 200.3kW×1 hr ÷45 Ltr = *4.45 units/ Ltr (259.5/45 = 5.77 kVAh/litre).*

750 KVA DG Set-III:

Mainly this generator is used to supply the Crusher Load of Nuagaon Iron Ore Block. Reading taken are:

Table 5: Voltage, Current, Power and PF of 750 kVA DG Set-III

	L_1	**L_2**	**L_3**	**Total***
Voltage	238.2 V	238.7 V	238.7 V	
Current	609.8 A	628.8 A	623.6 A	
Power*	145.3 KVA 92.96 kW 111.6 KVAr	150.1 KVA 89.84 kW 120.2 KVAr	148.9 KVA 86.07 kW 121.5 KVAr	444.2 KVA 268.9 kW 353.3 KVAr
PF*	0.64	0.60	0.58	0.61

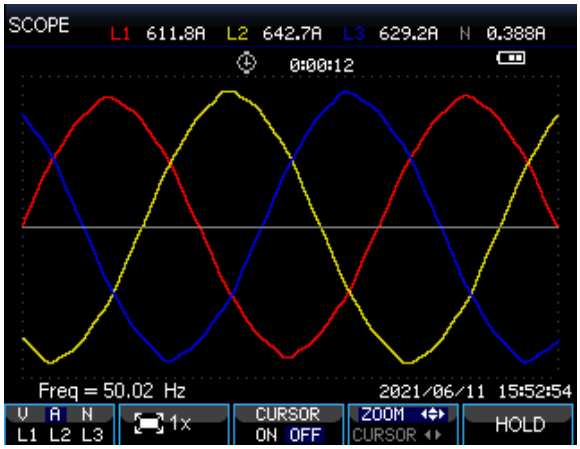

Figure 5: Current Waveform of Loads connected to 750kVA DG Set-III

Observations:

I. Mainly 3-ϕ loads are connected to this DG set, so the loads to all three phases are almost balanced.

II. During analysing the performance, it is found operating with 444.2 kVA load which is 59.2% of its loading capacity.

III. Its operating power Factor is 0.61, which can be improved to 0.8, the rated operating power factor of Generator. This reduces the loading capacity of the generator and increases its fuel consumption.

Calculation of Diesel Consumption:

As the diesel consumption of this Generator is 90 litres/hour, while operating with 268.9 kW Load. Hence it's *Diesel consumption rate* in terms of UNIT is: 268.9kW×1 hr ÷90 Ltr = *2.98 units/ Ltr (444.2/90 = 4.94 kVAh/litre).*

Power Factor Improvement and Calculation of Required kVAr:

As the rated Power Factor of Generator is 0.8 and it is operating on 0.61 pf, so need to improve to 0.8. As the real power supplied by this Generator is 268.9 kW Current operating Power Factor $cos\boldsymbol{\phi}1$=0.61 i.e. $\boldsymbol{\phi}1$= 52.410 Desired Power Factor $cos\boldsymbol{\phi}2$=0.8 i.e. $\boldsymbol{\phi}2$= 36.860

Hence *Required kVAr*= Power Consumed in 268.9 × (tan$\boldsymbol{\phi}$1- tan$\boldsymbol{\phi}$2) = 268.9× (tan 52.410- tan 36.860) = *147 kVAr i.e 150 kVAr* Cost of kVAr (Thyristor controlled, 440V) = Rs.1350/kVAr

Hence cost of 150 kVAr capacitor bank = 1350x150 = Rs.2,02,500/-

Potential Savings calculation:

Improvement of power factor from 0.61 to 0.8 will reduce the apparent power from 444.2 kVA to 336 kVA.

Hence savings in diesel = (442-336)/4.94 = 21.4 litres/hr. Considering diesel cost @Rs.93/litre, savings = Rs.1990/hour.

500 KVA DG Set-III:

The connected loads to this DG set are three units of the Screening Plant of Nuagaon Iron Ore Block. Reading taken are:

Table 6: Voltage, Current, Power and PF of 500 kVA DG Set-III

	L_1	**L_2**	**L_3**	**Total***
Voltage	223.3 V	233.6 V	228.6 V	
Current	73.55 A	33.57 A	84.06 A	
Power*	16.48 KVA 16.10 kW 3.495 KVAr	7.828 KVA 7.802 kW 0.643 KVAr	19.20 KVA 18.98 kW 2.891 KVAr	43.88 KVA 42.88 kW 7.029 KVAr
PF*	0.98	1.00	0.99	0.99

Observations:

I. Mainly 3-ϕ loads are connected to this DG set, so the loads to all three phases are almost balanced.

II. During analysing the performance, it is found operating with 444.2 kVA load which is 59.2% of its loading capacity.

III. Its operating power Factor is 0.61, which can be improved to 0.8, the rated operating power factor of Generator. This reduces the loading capacity of the generator and increases its fuel consumption.

Calculation of Diesel Consumption:

As the diesel consumption of this Generator is 90 litres/hour, while operating with 268.9 kW Load. Hence it's *Diesel consumption rate* in terms of UNIT is: 268.9kW×1 hr ÷90 Ltr = *2.98 units/ Ltr (444.2/90 = 4.94 kVAh/litre).* Power Factor Improvement and Calculation of Required kVAr:

As the rated Power Factor of Generator is 0.8 and it is operating on 0.61 pf, so need to improve to 0.8. As the real power supplied by this Generator is 268.9 kW Current operating Power Factor $cos\boldsymbol{\phi}1$=0.61 i.e. $\boldsymbol{\phi}1$= 52.410 Desired Power Factor $cos\boldsymbol{\phi}2$=0.8 i.e. $\boldsymbol{\phi}2$= 36.860

Hence *Required kVAr*= Power Consumed in 268.9 × (tan$\boldsymbol{\phi}1$- tan$\boldsymbol{\phi}2$) = 268.9× (tan 52.410- tan 36.860) = *147 kVAr i.e 150 kVAr*

Cost of kVAr (Thyristor controlled, 440V) = Rs.1350/kVAr Hence cost of 150 kVAr capacitor bank = 1350x150 = Rs.2,02,500/-

Potential Savings calculation:
Improvement of power factor from 0.61 to 0.8 will reduce the apparent power from 444.2 kVA to 336 kVA. Hence savings in diesel = (442-336)/4.94 = 21.4 litres/hr. Considering diesel cost @Rs.93/litre, savings = Rs.1990/hour.

500 KVA DG Set-III:
The connected loads to this DG set are three units of the Screening Plant of Nuagaon Iron Ore Block. Reading taken are:
Observations:

I. Both 1-Φ and 3-Φ loads are connected to this DG Set, less load is connected to Y-phase, so *need to reshuffle all the loads to its all phases*.
II. During analysing the performance, it is operating with 43.50 KVA load which is 8.7% of it's *loading capacity*, which is *very poor need to connect some other loads*.
III. Its operating power Factor is 0.99.

Calculation of Diesel Consumption:
As the diesel consumption of this Generator is 40 litres/hour, while operating with 42.88 kW Load. Hence it's *Diesel consumption rate* in terms of UNIT is: 42.88 kW×1 hr ÷40 Ltr = *1.07 units/ Ltr.*

III. CONCLUSIONS

The performance of different 750 KVA and 500 KVA DG Sets are analysed. They have different Loading Conditions and Operating Power Factors. The 500 KVA DG Set-II and 500 KVA DG Set-III have good Operating Power Factor and so they have no scope of Energy Saving in terms of Power Factor Improvement, however there is scope to improve the Loading Condition to improve the performance in terms of Energy Saving. 750 KVA DG Set-I, 500 KVA DG Set-I, 750 KVA DG Set-II, 750 KVA DG Set-III are operating on poor Power Factor, so energy can be saved by using appropriate Rating of Capacitor Banks as per given detail in the paper. The collective savings in terms of Money with Diesel Price Rate 93/- per Litter, are 1562+1553+2631.9+1990= 7736.9/- per hour.

List of Instruments used for Analysis:
(All instruments are calibrated)
1. 3-Phase Power Analyzer
Make: Kusam-Meco. Model: KM2200
Voltage Range: 1000 V
Current Range: 1000 A
2. Single Phase Power Analyzer
Make: Kusam-Meco. Model: KM351/BM351

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