

CAPTIVE GENSETS DON'T NEED CAPACITORS – RIGHT? WRONG!

SYNOPSIS:

The application of LT capacitor banks for the twin objectives of reducing kVA demand from the utility and effecting voltage improvement in the LT network has frequently caused Genset users into believing that capacitors are superfluous when Gensets operate in standalone mode.

What is often not realized is that Gensets have limited ability to meet sudden, large demands of reactive power as in encountered in certain process industries. This results in sizing the Genset too liberally, leading to high capital cost. Moreover, the running costs are high too, due to part-load efficiencies of Gensets being very poor. Part load operation affects engine life as well. Judicious application of fast acting capacitive compensation can be beneficial to users on all counts.

This paper describes the reactive power requirements imposed on Gensets by different types of loads, their effect on the engine and the generator and the role of dynamic compensation in optimising the investment on Gensets.

1. INTRODUCTION:

1.1 The role of power capacitors in improving the power factor and reducing total cost of electricity in an industrial installation is well established with regard to supply of power from the electricity boards/utilities.

1.2 It is thus logical to extend the above application of power capacitors when power is drawn from captive diesel gensets to optimise their performance.

1.3 It is, however, a common practice that DG set users generally switch off capacitors or do not install capacitors at all when the DG set is in use.

1.4 The primary reason for this situation is the general opinion that capacitors should not be used along with the loads when the DG set is in operation.

1.5 The basis for such an opinion is the apprehension that the DG set may get over loaded due to the fact that the current delivered by the DG set is generally considered as the indicator of output by most DG set users. It is well known that use of capacitors will reduce the current drawn from the DG set and could thus tempt the user to add more loads on a given DG set. The other reason for such an opinion is related to the risks arising due to sustained leading power factor conditions that would occur with the use of fixed capacitors in variable load situations. The ill effects of leading power factor on the behaviour of the DG sets are well recognised.

1.6 Technological developments in the recent years have, however, resulted in development of suitable capacitor based REACTIVE POWER COMPENSATION (RPC) Systems which are capable of being used along with DG sets in a reliable and safe manner.

1.7 It is also observed that judicious application of this modern technology can improve the overall efficiency of DG set operation and result in considerable economic benefits to the DG set user.

1.8 This paper therefore outlines the various factors which influence the economics of operation of DG sets and then proceeds to identify the specific REACTIVE POWER COMPENSATION solutions which could be used to achieve a reduction in cost of energy generated by DG sets.

2. RELEVANCE OF 0.8 POWER FACTOR:

It is widely believed that the average power factor at which a DG Set should operate is 0.8. The facts stated below are specifically to correct this is technically erroneous conclusion.

2.1 Alternators are rated in Volt-Amperes (kVA). This is logical in the sense that it specifies the maximum current the alternator can deliver at the system voltage.

2.2 To specify the appropriate power rating of a diesel engine for a particular Alternator we have to first convert kVA to kW and thereafter kW to BHP. This can only be done if we assume a certain average Power Factor (PF) under which the DG set would operate.

2.3 The power factor so assumed should be in line with the average power factor prevalent in the industry. A typical industrial load comprises of induction motors (typical PF of 0.8 to 0.85), non-linear loads (typical PF of 0.5 to 0.6) and combination of unity PF loads (Resistive heating and incandescent lighting). Hence assuming an average power factor of 0.8 for typical industrial loads is considered acceptable by convention.

2.4 Consequently a power factor of 0.8 is used for calculating the kW, which is then converted to the BHP rating of the prime mover. Knowing the BHP it is now possible to calculate the power rating of the engine.

2.5 It is, however, important to ensure that under actual operating conditions the kW loading and current loading should not be exceeded.

2.6 Power Factor of loads supplied by DG sets can therefore be improved closer to unity by use of suitable Reactive Power Compensation Systems keeping in view the conditions stated in 2.5.

3. Parameters Influencing Economics of DG Set Operation:

The two major factors that influence the economics of DG set operation are:

- Mechanical Factors
- Electrical Factors

The mechanical factors are related to the various engine aspects such as, proper lubrication, cooling, air intake systems, maintenance etc., since these issues are considered common to all situations and they are not dealt with in this paper. It however is to be understood that for proper performance of the engine these factors are paramount and should be addressed with great care on a continuous basis.

The electrical factors can be broadly classified into the following:

- Alternator Efficiency
- Power losses occurring in the electrical distribution network.
- Average kW loading on the DG Set.

3.1. Alternator Efficiency:

The efficiency of an alternator is a function of the total losses that occur within the alternator. For practical purpose we can consider these as iron and copper losses, since other losses such as windage and friction losses etc are negligible. The iron losses are generally considered to be constant irrespective of loading of the machine. However the copper losses in the alternator are proportional to the square of the current delivered by it.

Hence any reduction in current supplied by the alternator shall result in reduced losses. These losses shall be equivalent to a given amount of energy, which is a function of the time for which the alternator operates. Since this energy is supplied by the prime mover, loss reduction ultimately leads to lesser fuel consumption. The simplest technology for reducing current in a given load is to ensure that it operates at the highest feasible power factor.

The following example gives an approximate calculation to show the impact of improvement of alternator efficiency:

Consider a 3 Phase, 415V, 50Hz, 500 kVA DG set used in an Industry for 6000 hours/year with an average load of approximately 250 kW at 0.65 PF. What is the fuel saving if PF is improved to 0.93? The full load copper loss of the alternator is 12 kW and average yield of the DG set is 3 kWh / litre of fuel (HSD).

Rated Current of Alternator = 695.60 A

Current at 0.65 PF = 535 A

Copper loss at this current = 7.1 kW

Current at 0.93 PF = 374 A

Copper loss at this current = 3.5 kW

Saving in copper losses = 7.1-3.5 kW

= 3.6 kW

For 6000 hour operation = 3.6 x 6000 kWh

= 21,600 kWh

DG set yield = 3 kWh / litre of HSD,

Potential Saving in HSD fuel = 21600/3 litres per year

= 7,200 litres per year

Potential Savings in Rs. @ Rs. 15 / litre = Rs. 1,08,000 per year.

After due consideration to changes in loading pattern, losses occurring in P.F improvement systems etc., practically about 50% of this saving can be achieved.

The equipment required to achieve this power factor improvement is a REACTIVE POWER COMPENSATION system, the pay back period for which could be less than 2 years. The risks of overloading of the DG Set and sustained leading Power Factor conditions occurring are totally eliminated with the use of this technology.

NOTE: It is to be ensured under all operating conditions that the effective kW loading of the machine should never exceed the capability of the prime mover irrespective of all other issues.

3.2. Power Losses occurring in the Electrical distribution network:

The total losses occurring in the electrical distribution network, is a function of the current flowing through the network and the resistance offered by the current carrying conductors/switchgear used.

Consequently, reduction of current can be realised by installing RPC Systems in the network as close to the load as feasible. This will have the added benefit of reducing losses between the alternator and the point of connection of the RPC Systems thereby resulting in further fuel savings.

While the exact savings will be case specific to each network, it will be reasonably accurate to say that savings similar to those mentioned in 3.1 can be achieved by the use of a well-engineered scheme.

3.3. Average kW loading pattern on the alternator:

3.3.1 This is the most significant factor in terms of the fuel consumed by a DG set. One can get a graph from the DG Set manufacturer that gives a typical curve of kWh/litre yield of DG sets versus the percentage loading of the set. It can be seen from the graph that most optimum performance is achieved as the loading tends towards 80% of the capability of the machine. Consequently, it should be the endeavour of all the DG set users, particularly those who are using the set as the prime source of power supply, to achieve optimum loading.

3.3.2 In order to understand typical loading pattern of DG sets, it is necessary to go into the process of how a DG set rating is selected. The selection process of a DG set involves the following steps:

- **STEP 1:** Listing of all loads in terms of their operating kW and Power Factor.
- **STEP 2:** Aggregate loading based on the step 1 multiplied by a suitable demand factor. (Since all loads may not operate simultaneously).
- **STEP 3:** Providing additional kW capacity to meet short term peak load requirements which arise due to various load characteristics such as starting of induction motors, operation of traction loads such as lifts, cranes etc., intermittent operation of welding machines etc.,
- **STEP 4:** Providing yet more additional kW capacity in the form of a derating factor, due to the fact that some loads are harmonic generating loads. Typical examples are DC motors, variable speed drives and other devices, which have thyristor based operation.
- **STEP 5:** Provision of additional kW capacity to meet future needs.

Consequently, the resultant rating of the DG set arrived at by this process is generally higher than needed for regular operation. It is, therefore, quite common to find that most DG sets are loaded only between 40 to 60% of their capacity for a majority of the operating period.

As a result the practical kWh /litre of HSD achieved is lower than the actual capability of the machine. It is therefore obvious that if the loading can be increased significant savings in fuel economy can be achieved.

For example: -

- If total units generated = 10,00,000 kWh/year

HSD Consumption @ 60% loading = $10,00,000/3.0$ litres

= 3,33,335 litres

HSD Consumption @ 80% loading = $10,00,000/3.6$ litres

= 2,77,780 litres

- Annual Savings in HSD = 55,555 litres

- Annual Savings in Rs. = $55,555 \times \text{Rs.}15/\text{litre}$

= Rs. 8,33,325 /-

- Saving in Rs./kWh = Rs. 0.83 per unit generated.

REACTIVE POWER COMPENSATION SYSTEMS can enable D.G set users to reconfigure their loads / D.G sets to achieve better percentage loading on the machines. As a result reduction in cost / kWh can be attained.

4 In order to highlight the practical issues and benefits involved in using RPC SYSTEMS,

typical cases are given below:

4.1 Case 1:

4.1.1 PROBLEM:

An Industry has power supply connection from the Electricity Board and has a captive DG set, which is used if there is an interruption in Electricity Board Power Supply or when incoming Power Quality is considered unsuitable. The DG set, therefore, operates for an average of 2000 hrs per year.

This industry has a 250 kVA DG set which is loaded at an average of 120 kW at 0.7 PF. In addition, there are 40 kW of other loads within the same installation, which are not loaded on the DG set due to capacity restrictions that arise during occurrence of short-term peak loads, such as motor starting, and intermittent welding load.

Due to this, productivity in the Industry is lowered when the DG Set is in operation.

During the period when Electricity Board supply is available all loads can be operated.

Is it possible to:

- **Reduce the cost of electricity consumed from the Electricity Board?**
- **Improve Productivity when DG Set is in operation?**
- **Reduce the cost of electricity generated by the DG Set?**

4.1.2 SOLUTION:

A well-designed Reactive Power Compensation Scheme can provide the solution as follows:

- During the period when the Industry is using supply from the Electricity Board the RPC system can ensure consistently high PF, thereby achieving demand savings and reduction in losses and elimination of any PF penalty. Consequently, cost of electricity consumed from the EB will be minimised.
- The same RPC system can be also used when the Industry is using supply from the DG set.

- The fast acting property of the RPC system will reduce the peak load requirements that are to be met from the DG set. This is achieved by providing instantaneous compensation from the RPC system during conditions when motors are started and / or welding machines are being operated. This will enable the Industry to transfer the 40 kW of additional load on to the DG set and ensure that productivity is improved when the DG set is in operation.
- Due to better loading, the DG set efficiency will improve in line with the graph. Consequently the cost per unit of Electricity generated by the DG set will reduce from Rs. 5.30/kWh to Rs 4.50/kWh i.e. a saving of 15% as explained below.
- Before the use of RPC System, the loading factor of DG set was 60%, consequently giving an yield of 3 kWh/litre. Taking into account Rs. 0.30/unit of electricity generated towards the cost of maintenance and upkeeping of DG set, the cost per unit of electricity generated works out to be Rs. 5.30/kWh.
- After connecting the RPC system and transferring the additional 40 kW load to DG, the loading factor would improve to 80% and consequently the yield would improve to 3.6 kWh/litre. Taking into account the cost of maintenance of DG, the cost per unit of electricity generated works out to be Rs. 4.50/kWh.
- Hence a net saving of Rs. 0.80/kWh generated i.e., a saving of approximately 15% is achieved.

4.2 Case 2:

4.2.1 PROBLEM:

An Industry has no power supply connection from the local Electricity Board. It has captive DG sets that are used as the supply source. The DG sets, therefore, operate for an average of 5000 hrs per year.

This industry has a 1 x 1000 kVA + 2 x 500 kVA DG sets operating in parallel and loaded at an average of 960 kW at 0.7 PF.

The loading of DG sets is done keeping a provision for short- term peak load requirements that arise due to starting of induction motors, and operation of lifting cranes. In addition extra provision is also made for certain non-linear loads (thyristor loads) which generate harmonics i.e. DC motors and UPS systems. The total energy generated per year is 48,00,000 kWh. Total fuel + maintenance costs of the DG Sets is Rs. 255 lakhs per year resulting in a cost of Rs. 5.31 per kWh.

- Can the cost of electricity generated by the DG Set be reduced?

4.2.2 SOLUTION:

A well designed Reactive Power Compensation and Active Filter System can provide the solution as follows:

- The fast acting property of the RPC system will reduce the peak load requirements that are to be met from the DG set. This is achieved by providing instantaneous compensation from the RPC system during conditions when motor starting/crane operation is taking place.
- The harmonics generated by the non-linear loads will be eliminated by the Active Filter System
- Lastly the current drawn from the DG Sets will reduce
- Consequently the same 960 kW load can now be supplied from 1 x1000 kVA +1 x 500 kVA operating in parallel.
- One 500 kVA DG set need not be operated.
- Due to better loading, the DG set efficiency will improve. Consequently, the cost per unit of electricity generated by the DG set will reduce as shown in the calculation below.
- DG Sets were initially operating at 60% loading factor. The DG set yield at 60% loading factor is 3 kWh / Litre. The total diesel consumption for 1 no. 1000 kVA and 2 no's 500 kVA DG set is 16,00,000 litres.
- When the 960 kW load is transferred to 1 no. 1000 kVA and 1 no. 500 kVA DG sets, the loading factor will improve to 80% and the DG set yield will be now 3.6 kWh / litre. The total diesel consumption will be now 13,40,000 litres.
- The annual saving in diesel consumption will be 2,60,000 litres, which amounts to approximately Rs.40 Lakhs per year.
- Total savings per year (5000 hrs. operation) = Rs. 40 Lakhs.
- Taking into account a fixed cost of Rs. 0.30 / kWh towards maintenance and upkeep of DG set, the net savings / kWh of generation of electricity works out to be Rs. 0.80 / kWh. This is about 15 % of saving.

5. Reactive Power Compensation and Active Filter Solutions

Reactive Power Compensation systems basically comprise of a microprocessor controller to sense the load power factor and/or Reactive power/ current and give commands to connect or disconnect the required kVAR to achieve the desired conditions as programmed in the controller.

The kVAR is provided by suitably sized power capacitors / reactors arranged in appropriate steps. The RPC system hence should have suitable switching devices to

connect or disconnect the power capacitors along with protection devices like fuses and relays.

The type of switching and controlling devices used in RPC system depends upon how fast the reactive power is to be introduced into or withdrawn from the electrical system. This, in turn, is dependent upon the type of electrical load to be compensated.

If the response time " t_r " of the system is greater than or equal to 5 seconds, contactor switching with suitable discharge devices can be used. However if " t_r " is less than 5 seconds, controlled switching using thyristors is required. If " t_r " is less than or equal to 1 second, it is necessary to use a fast acting special purpose controller to operate the whole system.

The contactor-switched Reactive Power compensation systems are popularly referred to as **Automatic Power Factor Correction (APFC) systems**.

The thyristor switched systems are known as **Dynamic Compensation Systems (DCS)**.

5.1 Contactor Switched APFC Systems:

APFC systems have a response time, which is quite sufficient for fairly steady and / or slow varying loads. When a contactor switches off a capacitor, a voltage equal to the value of line voltage at the instant of switching off, is retained at the capacitor terminals. Before this capacitor can be reconnected, sufficient time has to be given for the terminal voltage across it to discharge to a safe value, so as to avoid damaging the capacitor.

5.2 Dynamic Compensation

This system features controlled switching of power capacitors using thyristors and associated control / firing circuits for reduced response time. In this system, it is possible to switch in capacitors at the instant when its voltage is equal to that of line voltage, thereby eliminating the need for capacitors to discharge. Based upon the point of sensing dynamic compensation system can be classified as **Open** or **Closed** loop.

5.2.1 Open Loop

If the load operation / switching is sensed directly and feedback given to the dynamic compensation system, this is termed as open loop dynamic compensation system. The response time in this arrangement is very short and hence this scheme is usually used for instantaneous compensation. It is also possible to operate this system by an external command, which is given just before the operation of the load. Consequently this system can be operated in " pre- trigger " mode and therefore has the smallest response time.

5.2.2 Closed Loop

If the load conditions are sensed as the combination of load and capacitor currents, then this is termed as closed loop dynamic compensation. In this arrangement the dynamic compensation system works similar to a contactor switched APFC system, but with a much faster response.

5.3 Active Filter

Active filter is the state of the art technology solution for eliminating harmonics generated from LT non-linear loads, like variable frequency drives, UPS, etc. The active filter works on the principle of generating counter-harmonic currents in phase opposition to that generated by the non-linear load which results in cancellation of all harmonic currents. Thus the non-linear load in combination with active filter presents itself as a harmonic free load to the network. The active filter adapts itself to the requirements of the load on a continuous real time basis.

6. CONCLUSION

It is a general practice to oversize the rating of Diesel Generator Sets due to various technical and other reasons.

Over-sizing results in a lower loading factor on DG Sets during their normal operation, leading to increased running cost. Various other issues such as load sharing, escalating fuel cost also have adverse impact in terms of productivity and profitability for the DG Set user.

It has been a practice to avoid the use of capacitors in networks that are supplied by DG Sets.

The evolution of Capacitor Application technology as outlined in this paper makes it practical to improve loading factor on DG sets, reduce power losses and finally, lower the cost per kWh generated.

The judicious use of well-engineered capacitor based Reactive Power Compensation technologies can therefore result in improved DG set performance, reduced energy cost and better productivity in installations / networks supplied by Diesel Generating Sets.