

HYBRID REACTIVE POWER CONTROL, APPLYING STATIC AND DYNAMIC COMPENSATION SCHEMES TO A STEEL PLANT.

V. N. Agu,
Department of Electrical Engineering,
Nnamdi Azikiwe University, Awka.

Abstract

This report presents the implementation of hybrid reactive power control employing static and dynamic compensation schemes in a modernization and expansion project of a steel plant power facility. The scheme studies existing network reactive power behaviour and that of incoming loads to effect a design applying synchronous phase advancer for analogue reactive power control to loads of matching reactive power profile and stepped capacitive reactive power control to others adaptive to it. In the end, a high efficient and a cost optimized reactive power scheme is adopted with release of up to 10.73% of existing system capacity for additional loading.

1.0 Introduction

The Nigersteel company is a steel company with Electric Arc Furnaces and Rolling Mills whose single line network is shown in fig.1. The company operated a load of very fluctuating nature (the electric arc furnaces). So both its megavolt amperes and power factor(p.f) fluctuate under normal operating conditions. Due to the nature of electric arc steel making, a p.f of 0.707 to 0.85 is usually considered of optimal economy because; [1] (i) maximum power is attainable at 0.707 p.f (ii) rated KVA can only be attained at 0.85 p.f (iii) p.f decreased rapidly with increase in the arc currents beyond the value which gives an 0.85 p.f while the corresponding rate of power increase is small(iv) correction beyond 0.95p.f becomes uneconomical. During measurements at the factory, table1 was developed and it was observed that without compensation, p.f values range from 0.5 to 0.7 during operation though much longer in the lower ranges of plant operation.

2.0 Power Factor Correction for the Arc Furnaces

From ratings on equipment, the arc furnace load represents 99.9% of installed capacity. Due to errors of quantized under correction and overcorrection, a choice always has to be made between; (i) automatic capacitor bank providing varying KVAR in incremental steps (ii) a synchronous compensator

providing varying analogue KVAR generation or absorption.

Table 1. Load Schedule Summary of Plant

S/N	Equipment	Load	Power Factor
1a	Furnace	2 x 3600KVA	0.5 - 0.7
1b	Furnace Auxiliary	285.75KW	0.8
2a	Rolling Mills	890KW	0.85
2b	Mill Auxiliary	302.6KW	0.8

3.0 Determination of Kvar Injection

The power bill of the company was studied and the highest demand of 2.75MV occurred in the month of February, 1979 within the 24 month period of the tariff.

Considering a worst case p.f of 0.5 to be corrected for a load of 2.75MVA up to 0.95 p.f, we determine the KVAR demand as follows: MW from 2.75MVA at 0.5 p.f = $2.75 \times 0.5 = 1.37\text{MW}$ $\times 0.85 = 1.1645\text{MW}$ Hence, we have a load of 1.1645MV at 0.5 p.f to be corrected at 0.95 p.f.

The VAR injection required for a load of P KW correcting from p.f $\cos\phi_1$ to $\cos\phi_2$ is given by

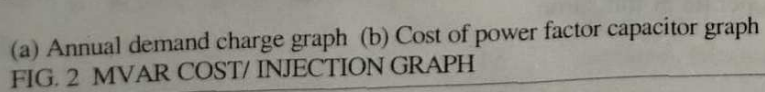
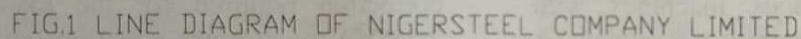
$$\text{VAR} = P(\tan\phi_2 - \tan\phi_1) \quad \dots(1)$$

giving

$$1.1645 \times 1.403 = 1.6337\text{MVAR}$$

this is the extreme case.

A p.f of 0.85 had already been considered adequate for Electric Arc Furnaces from point of power utilization in electric arc furnaces. The provision of separate correction equipment for the Mills and Furnaces was determined from the foregoing considerations.



- (i) The use of automatic capacitor bank at the 33KV level will imply that only necessary capacitance is switched unto the line even for the smallest amount of load in circuit with only step deviation error. The disadvantage is that the 2.5MVA and 500KVA transformers will still carry the full KVAR of their loads hence not releasing extra transformer capacities for expansion[2]. The prime consideration is to obtain extra capacity from this transformer so we need to inject correcting KVAR at the 6.6KV bus. To obtain maximum benefit, we need two correction equipment; one at 33KV bus level and one at 6.6KV level.
- (ii) The use of synchronous compensator implies that if the machine be located at the 33KV bus, it must be run for even the smallest load. This is absurd when the losses in a 1.8MVAR compensator for instance is compared with the savings obtained from compensating for the crane loads which may be required to run without the furnaces. Also, the cost benefits of having a number of smaller automatic synchronous machines with extensive control system is not prudent. A full picture of the correction cost determination using shows the annual demand charge at 33KV using the 1989 tariff [3]. Is shown in Fig. 2 graph a.

The costs of p.f capacitors are also plotted into fig.2 graph b. This gives a direct idea of the cost as determined from the 1989 tariff. Classically, p.f correction is usually a technical and economic decision. This approach touches on: (i) reduction in maximum demand charge, (ii) reduction in system losses, (iii) released system capacity.

4.0 Optimal Solution

As can be seen in fig.1, the company already has a synchronous compensator of 1.8MVAR which can handle the calculated reactive current demand for the operation of the electric arc furnaces whose maximum demand is at 1.6337MVAR. This means that an extra capacitor need be acquired for the Billet/Slab Continuous Casting Machine and other ancillary equipment. Both Caster and Loop Mill drives usually operate at the same

time so they can be compensated as a group. For reasons of cost, the choice between a synchronous machine and a capacitor bank is easily made in favour of a capacitor bank.

5.0 Location of the Capacitor Bank

From the foregoing, and looking at fig.1, the capacitor location will inevitably be at the 6.6KV bus. So a 6.6KV capacitor bank is chosen. The 2.5MVA transformer is now relieved of the reactive KVA enabling it to handle more load than otherwise. Since there are four breaker units on this voltage level (6.6KV bus), the extra capacity released from the 2.5KVA transformer will enable extra loading on any spare of the four feeders connected to secondary 6.6KV bus. The most accurate method of determine the original/operating p.f of a system to be corrected is by measurement. This is because the various electric motors may not be operating at full load and so the name plate data (including the p.f) are not exact.

However, it is advisable to provide capacitor banks capable of correcting up to full load ratings of the motors. To determine the correction required for the loads on the 2.5MVA transformer, equation 1 still applies:

5.1 Caster/Mill Load

The modernization and expansion programme of the plant removes the loads M2, M3 and some of their auxiliaries to introduce the new caster/mill load. This reduces the load on transformer T4 from 1478.35KW to 993.079KW to be corrected from 0.8 to 0.95 p.f.

Total KVAR needed to correct from 0.8 p.f up to 0.95 p.f = 418.4KVAR

5.2 Power Bill (Demand) Savings

The demand charge as obtained from fig. 2b is ₦3825/KVAR

The demand savings becomes ₦1600380

5.3 Cost of Capacitors

The cost of providing capacitors at 6.6KV level and for less than 1200KVA is ₦275/KVAR, hence for 85KVAR i.e. $185 \times 275 = 50875$

Total cost of capacitors = ₦186,972

6.0 Determination of Released System Capacity

Release of system capacity [2] applies to only transformer T4 in fig.1. This is due to the flow of full reactive power through transformers T5 and T8 behind which the capacitor bank is installed. It is observed that the correction of 993.079KW from 0.84 to 0.95 using yields a 27% saving of the transformer KW loading.

The resulting transformer capacity saving is: $993.079 \times 0.27 = 268.13\text{KVA}$

This means that the load of the 2.5MVA transformer has been reduced by 268.13KVA. This represents a saving of: 10.73% of transformer capacity.

In monetary terms, this implies 10.73% of the total cost of ₦1,206,800.00 for installing 33KV 2.5MVA transformer with switchgears, control panel, cable, corridor, terminations, space and labour estimated at ₦129489.64 has being saved.

Note: The cost of cables, bus section and space are here considered negligible due to shortness of cable and bus sections. The cost of the released system capacity is therefore ₦129489.64 and is that amount required to install a load capacity equivalent to the capacity released by the power factor capacitor addition.

6.1 Losses In Capacitor

When the value of the KVAR injection required is significant, the losses in the capacitor itself is estimated using [4]. From the figure, the loss for 0.420MVAR capacitor is on the maximum i.e. = 1500KWH priced at ₦660.00

6.2 Summary of Cost Analysis

Table 2. Cost Analysis

	Saving ₦	Losses ₦
Power bill savings	1600380	
System capacity savings	1206800	
Capacitor cost		186972
Losses in capacitor		660
	2807180	187632

Net savings = ₦2807180 - ₦187632 = ₦2619548

This is the picture in the first twelve months. After this period, the cost of capacitor should be replaced by cost of maintenance since the cost of capacitors must have been recovered in the first twelve months. As from the 2nd year of installation, let the cost of maintenance be put 5% of installation cost and the amortization of capacitors be at 10% per annum. So,

Cost of maintenance = 9348.6

Amortized cost of capacitors = 18697.2

Losses in capacitor = 660

28705.8

Net saving as from the second year becomes: $2807180 - 28705.8 = \text{₦}2778474.2$ per annum

7.0 Conclusion

From the above study, it is conclusive that the investments in power factor control facilities play directly to the technical and economic benefit objectives of the company. It is therefore recommended for implementation.

References

- [1] McLouth Steel Corporation, (1979), "Correction of Power Factor on Arc Furnace Circuit by Means of Shunt Capacitor Banks" Trenton, Michigan.
- [2] Westinghouse Electric Corporation, (1985), "Power Factor Correction Capacitors", T & D Corporation Division, Bloomington, Indiana.
- [3] National Electric Power Authority, (1979) "Electricity Tariff and Service Regulation", Nigeria.
- [4] Harder, John E., (1983) "Industrial Power Factor Capacitors: Estimating the energy cost savings", American Power Conference, Illinois, USA.
- [5] The Metallurgical Society, (1967), "Electric Furnace Steelmaking" American Institute of Mining, Metallurgical, and Petroleum Engineers.
- [6] Stevenson, William D. Jr. (1986) "Elements of Power System Analysis", 4th Edition, McGraw Hill Book Company, International Edition, Singapore.
- [7] Westinghouse Electric Corporation, "Rate Analysis", Distribution Apparatus Division. Bloomington, Indiana.