Achieving unity power factor at floating grid conditions in a cement plant in India – Case study

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***Abstract*—Most cement plants in India and around the world face a unique problem in regards with power factor. In industries where their local generation with their Captive Power Plant (CPP) and Waste Heat Recovery System (WHRS) is equal to or greater than the plant's total utilization, the load import from the Grid is brought down close to zero. This is done to reduce the power cost because the Grid power is comparatively expensive. Though the Grid power is not required, the connection to the Grid is mandatory for the system in floating mode to ensure the stability of the system, to avoid black-outs in the event of CPP failures/trips and to tackle unplanned/sudden variations in the load. Such a setup makes it extremely complex to maintain power factor at the Grid incomer. For more than a decade, it was assumed that no solution exists to this problem where CPPs are connected and power drawn from the Grid is close zero. In India, a state like Chhattisgarh, where Grid billing is in kVAh and on TOD[1] basis, power factor plays a major role in Grid cost optimization. This paper contains a discussion on the problem, the solution and a case study of achieving unity power factor at floating grid conditions in a cement plant in India.**

Keywords—Power factor, captive power plant, floating grid, Capacitor control, reactive power, active filter, Internet of things

I. INTRODUCTION

The primary focus of electric utility companies is the stable and economical operation of electric network. In the context of Indian electrical grid, it is the duty of the transmission and distribution authorities to maintain the efficiency and the quality of electricity. This responsibility, however, also spills over to the consumers as well. In order to operate an efficient and good quality electrical grid, the consumers must keep in check parameters within their control such as power factor and harmonics. The Utility therefore sets guidelines on the limits of such parameters by way of the billing system.

These factors will in turn have an effect on the consumers using this power from the electric network. Higher level tariff schemes are implemented for very large-scale industries and this tariff scheme takes into account the power factor of the industry. Lower power factor results in penalisation while higher power factor will be awarded incentives. Lately, there has been a wide awareness about harmonics and its effects on the Grid and consequently, Utility companies have started penalising high harmonic content also. IEEE-519 lays down the guidelines for the quantisation of harmonics and the methods of measurement as well.

This white paper looks at a peculiar, yet, rather common case in heavy industries in India. Cement/steel plants having generation capacity equivalent to their utilization, the grid (Utility supply) is connected only for stability and back up requirements. The nominal power requirements of the plant are fulfilled by the captive lower plant (CPP). The CPP supply is synchronized with the grid and the plant is operated on floating conditions where the grid loading is negligible. This loading is observed to be in the range of ±500kW while the plant utilization varies from 25MW to 100MW, or more. Feedback is taken from the Grid for governor [2] control [6][7][8][10], in order to maintain minimum MW import at the grid side. Figure-1 shows a typical cement plant configuration with CPP/waste heat recovery system (WHRS) of equivalent capacity as that of the load requirement.

[1]TOD – Time of Day billing system. It refers to the practice of setting different price for a of unit energy at different times of the day. The general classification is On-Peak, Off-Peak and Normal hours.

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[2]Governor is a steam pressure control for controlling the MW output of the Generator). In generator, there are two major control loops present, Active Power Control & Reactive Power/Voltage Control. The active power (MW) is controlled by varying the steam pressure/flow using Governor and reactive power (MVAr) is controlled by varying the excitation in the AVR (Automatic Voltage Controller) of the generator

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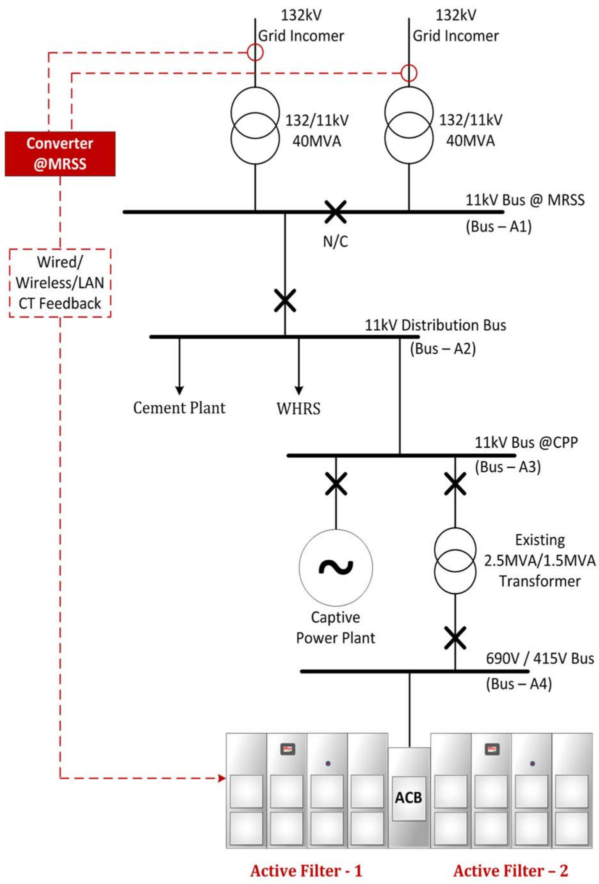

Fig.1 Typical solution with VAr compensator

It is to be noted that in metering system, when kW is positive (imported) and irrespective of whether the kilo-volt-ampere-reactive (kVAr) is exported (negative) or imported (positive), the kilo-volt-ampere (kVA) is always imported (positive). This deteriorates the overall PF, whereas when kW in exported, PF is maintained unity. The typical power triangle is shown in Figure-2.

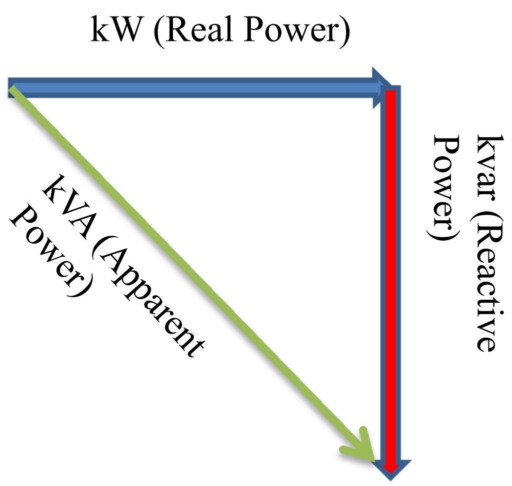

Fig.2 Power triangle of the power system

II. Related Work

There have been many works related to direct improvement of power factor by using compensators and analysis of the effect of compensators on the power parameters. Also, a number of projects have been tested out to indirectly improve the power factor by reducing the harmonics, proper loading and switching of power system equipments.

A. Power factor improvement and its effect

Paper [1] shows the effect of power losses, power factor and load waveform shape on the output curve from the solar panel and concludes that the power output reduces with higher relative power losses. Paper [2] gives a detailed description about the impact of power factor on a small scale renewable energy source. The paper has tested with different active and reactive power demands on the generating station and has also given a detailed cost analysis for each case.

B. Power quality improvement techniques and analysis

Most of the works are related to indirect method of improving power factor by eliminating harmonics by employing different techniques.

Paper [3] discusses the improvement of power factor in a micro scale wind turbine power plant by using two switch three phase LLC resonant circuit filter. Paper [4] gives an insight to optimised selective harmonic elimination for improving the quality of power supplied by using multiple resonant converters and digital control technique for harmonic filtering. Paper [5] discusses about the power quality mitigation and also efficiency improvement by using series hybrid passive filters. This mainly concentrates for current harmonic elimination in the system. Smart technologies are discussed in [9]. [11] suggests power flow control by power conditioning. Harmonic elimination by active power filters is discussed in paper [12]. [14][17] discuss the improvement of power quality by using dynamic voltage restorer. [15] discusses the power quality problems in large power plants. [16] analyses the power quality for a grid connected load.

III. Proposed System

The proposed system is similar to the one shown in Figure 1. The CPPs are being operated in constant power factor (PF) mode for kVAr control. During floating load conditions at the grid, the power import/export varies between ±500kW. This is continuously monitored and adjusted accordingly by the generator control system - governor for kW and automatic voltage restorer (AVR) for kVAr, in constant PF Mode. It means that the kW in the grid side often crosses zero during the process of import and export.

The application of the system by changing the position of the IGBT based compensator at main receiving substation (MRSS) is shown and also the cost estimation with and without power factor improvement is discussed in the following sections.

A. Challenges in the proposed system

For a load variation of about 1000kW, the challenges faced are as follows.

- The variation in the grid is not just a variation of a specific load, but the summation of the variations of many different loads in the entire plant.
- The variation in the kVAr of the plant includes the variations of the kVAr requirement of the loads, in addition to the generator kVAr generation or

consumption, which varies according to generator output due to PF mode operation.

- The variation in negative sequence current (unbalance) and harmonics are actually the resultant of the total load and distortion in power quality due to nearby plants (at the point of coupling) and not just the load in the plant [13].
- Any change in voltage across the plant will also vary the kVAr produced by each of the capacitor banks installed in the plant. More specifically, any variation will have square times the effect in kVAr as per the fundamental relationship as shown below

  $\text{kVAr of Capacitor} \propto V^2$

- Voltage change due to the loads connected to the supply will vary the reactive power generated/drawn by the generator/load as shown below.

  $\text{kVAr of Generator/Load } (\Delta Q) \propto \Delta V$

- Sudden connection or disconnection of any major load in the plant varies the voltage level, and therefore, kVAr. It is to be noted that this variation is in addition to the nominal kVAr requirement of the said equipment.
- The transformer through which the compensation kVAr is injected (whether leading or lagging) shall behave differently with the difference in the import or export condition of the plant.
- The control system elements in the compensation equipment (IGBT System) shall have a wide operating voltage band (in the range of ±25%). This is required because, when this equipment is compensating for the 132kV requirement, the step-up transformer is acting purely as an inductive or capacitive injector. In this condition, the secondary voltage of this transformer will have wide variations. These variations can damage the control electronics viz. integrated circuits (IC) supplies, voltage coils of trip circuit logics, printed circuit board (PCB), power supplies and other elements in the pulse width modulation (PWM) control circuit.
- The accuracy of the metering current transformer (CT)/potential transformer (PT) are designed for full load or partial loading conditions. The CTs, in particular, will be working under very minimal currents while the loading is close to zero. The best CT accuracy available in market is 0.2S, and even for that CT, operating range for accurate reading starts from 5% of the rating only. Hence, in case if the feedback is required from these CTs, it is necessary to make appropriate preparations and precautions in the compensation equipment for amplifier circuits with suitable range of operation, trip network etc.

B. IGBT compensator connection topologies

The different topologies for the proposed system are shown in the following figures. Figure 3 and Figure 4 are used when there are two grid side transformers on the incoming bus bar. Figure 5 and Figure 6 are proposed when there is oy one grid side transformer on the incoming side.

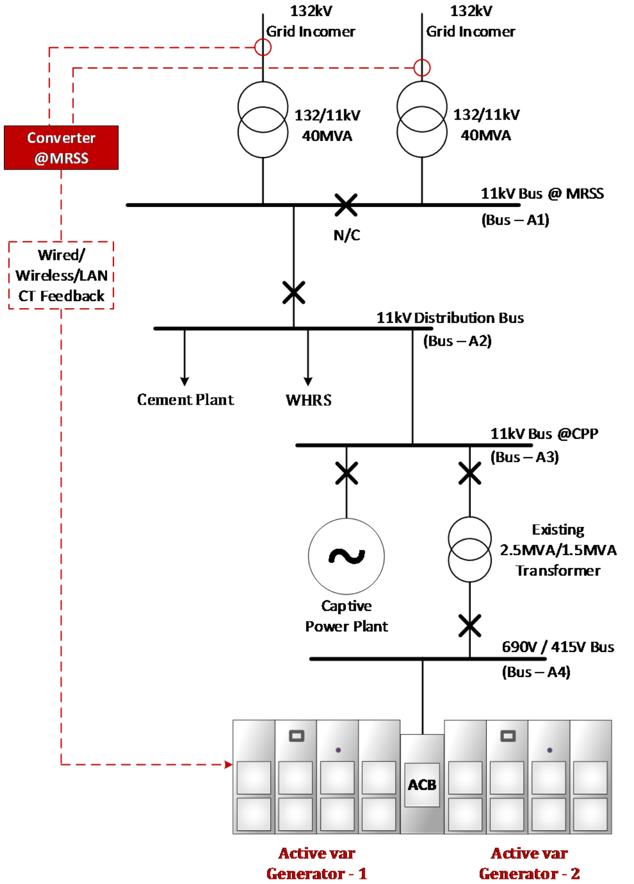

Fig.3 Two Grid Power Transformer and AVG Compensation at Load Centre

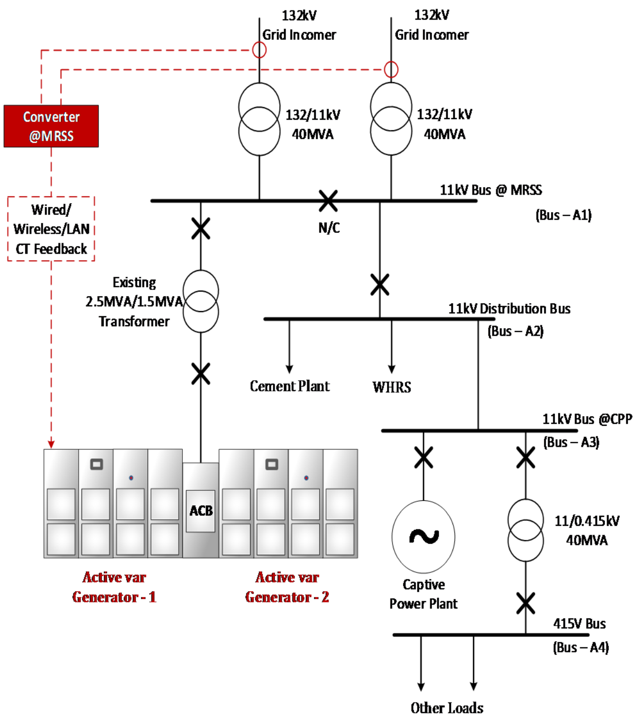

Fig.4 Two Grid Power Transformers and AVG Compensation at MRSS

Topologies shown in Figure 7 and Figure 8 are employed when either grid side transformer or CPP is present. The ACB component present acts as the net. Active VAr Generator (AVG).

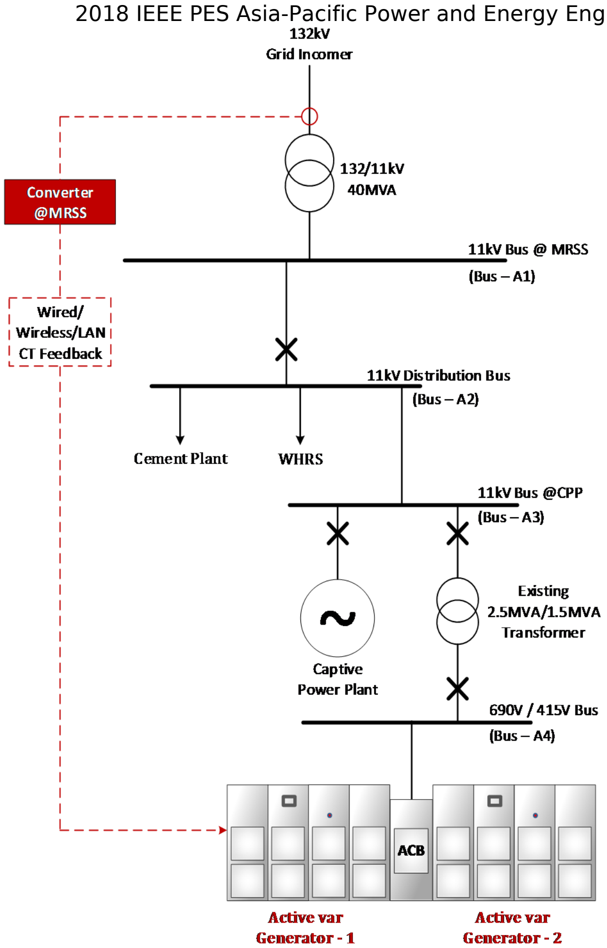

Fig.5 One Grid Power Transformer and AVG Compensation at Load Centre

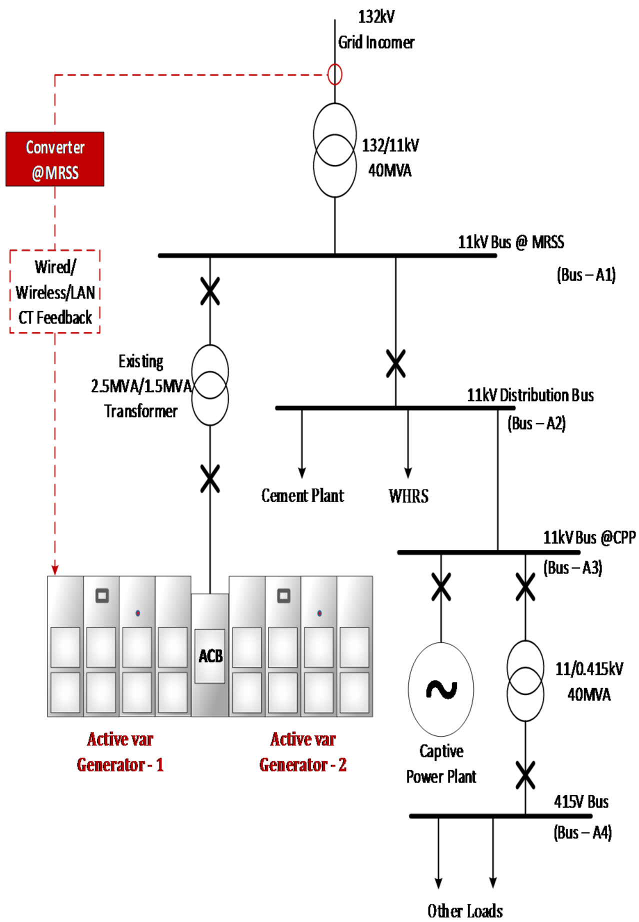

Fig.6 One Grid Power Transformer and AVG Compensation at MRSS

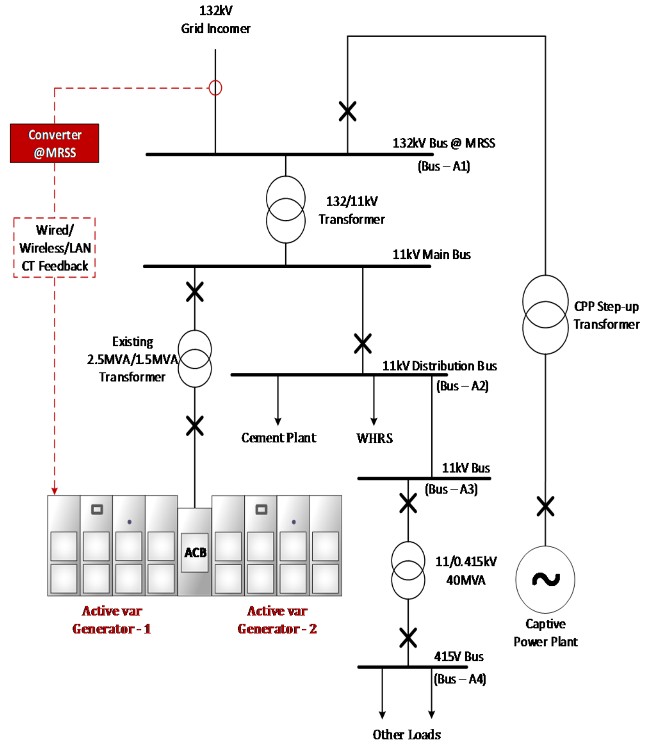

Fig.7 One Grid Power Transformer/CPP at 132kV and AVG Compensation at MRSS

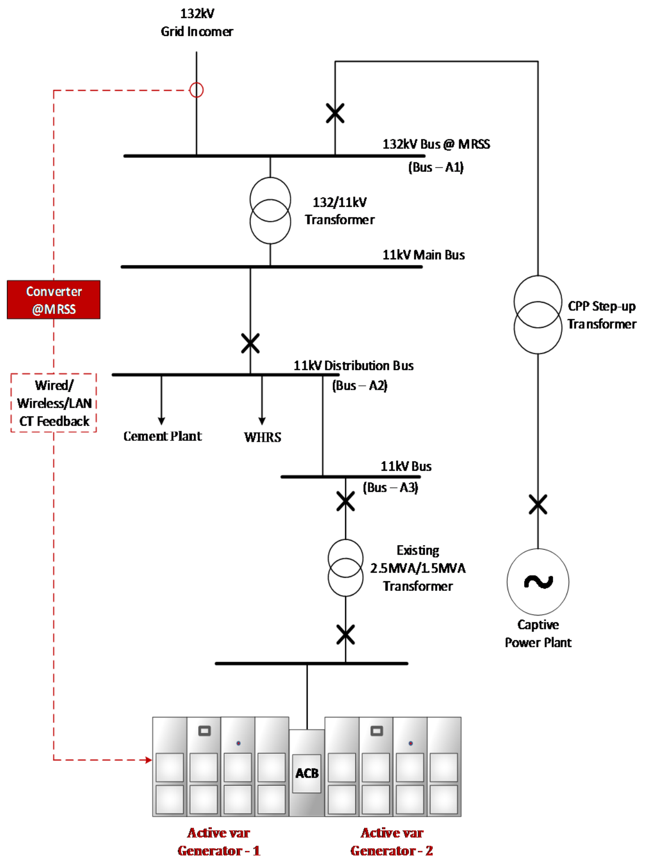

Fig.8 One Grid Power Transformer/CPP at 132kV and AVG Compensation at Load Centre

IV. RESULTS AND COST ESTIMATION

The results are shown in Figure 9, where it shows the kVAr of the plant at 132kV, before and after compensation by the equipment. This is achieved by synchronized measurement at MRSS (Main Receiving Sub Station) and

MDC (Main Distribution Centre). While the uncompensated kVAr is echoed in the latter, the compensated kVAr is reflected in the former.

The distinct trend of kVAr without compensation in red can be seen from Figure 9. This goes as high as 2000kVAr at some instances, while the compensated kVAr is negligible. It is to be noted that even though the fluctuation of the system is very

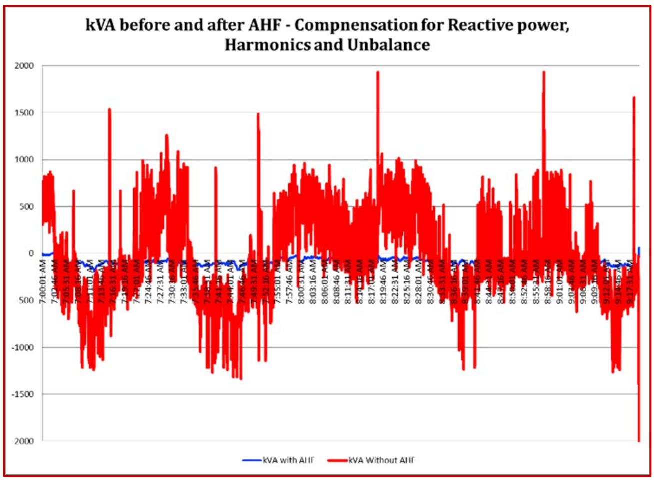

Fig.9 kVAr in network – with and without Active VAr Generator (AVG)

high and the plant operates in export/import condition, the active VAr generator has the capability to compensate in inductive/capacitive nature along with negative sequence components and harmonics at the same time.

The compensation equipment will only have a limited capacity of resource for reactive power, unbalance and harmonics. The majority of the compensation is still under the functioning of capacitor banks using the intelligent AVG controller with the gaps being filled by the active VAr generator itself. Compensating the kVAr of the system alone will not help in achieving unity power factor. It is a combined effect of the entire plant load. The equipment capacity installed in this specific plant is negligible. However, the cumulative effect of the compensation equipment in all the aspects of the plant control systems like Generator, DCS, and load shedding algorithms is what makes this a challenging problem.

The savings for this kind of scenario has three distinct type of direct savings, apart from the indirect savings. The indirect savings include line loss reduction in the cables, transformer loss reduction and reduction of overheating etc., in the main and auxiliary transformers. The direct savings are as follows:

- kVAh reduction due to the PF improvement (Direct bill savings)
- Savings by increased usage of CPP (Less import/export from Grid i.e. optimization).
- Savings due to reduction in generation duty of CPP, which is also in kVAh.

A. kVAh reduction by PF improvement

In general, when the loading in the grid is maintained at ±500kW, the typical number of units consumed in the Grid is about 10,000-20,000[3] units (kWh) per day. The Power Factor at that duration varies from 0.6-0.8 and on an average it is about 0.7.

Savings kVAh by PF Improvement = No of Units× (1/PF without AVG × –1/PF with AVG) ×Unit Cost

= 20,000 × 365 days × (1/0.70 – 1/0.95) × 6.75

= ₹ 18,524,436

Note that 0.99 and above is the PF with active VAr generator (AVG). During the operation, the PF varies due to other reasons. Hence PF is taken as an average value of 0.95 in the above calculations with AVG.

B. Savings by increased usage of CPP

Even though the industry doesn't require any power from Grid, in most industries, the practice is to import power in order to maintain Power Factor. In such condition for a plant of 35MW – 40MW having a maximum demand of about 10MVA to 15MVA, it is required to import at least 3MVA – 4MVA from the Grid on an average in order to maintain the average PF of at least 0.97 to 0.98.

In another analysis of plant data, on an average, the plant has to import 1.5-2 million units of power from the grid. (This data is purely based on plant data collected for many cement plants and not based on calculations. It might, however, vary from plant to plant depending on various parameters). The calculations below are based on the rigid fact of 2-3MVA import, on an average, as mentioned above.

Now, with the new IGBT based Active VAr Generators, the advanced algorithm and other minor customizations, the end customers shall import as less power as possible from the Grid. In such condition, the difference of power import earlier to later will have a cost reduction of about ₹2-2.4 per unit typically. This is achieved on account of production cost of power from the CPP being ₹4.35-5and cost of power from the Grid being ₹6.75-7 (As per the current market data available around the country for coal thermal power plants).

Savings by Increased Use of CPP = (Old Import– New Import) ×Unit Cost Savings

Old Import Units = 3,000 × 24 × 365 = 26,280,000 Units

New Import Units = 20,000 Units/day × 365 =7,300,000 Units

∴Savings by Increase in use = (26,280,000–7,300,000) ×2.4 = ₹ 45,552,000 (2)

This is a pessimistic calculation, based on the current available data of 3000kVA minimum demand in order to maintain an average PF of 0.95. However, in some plants, we have noticed that the yearly units can go as high as 3-4 million units.

C. Savings in generation duty of CPP

This is an additional benefit for the end customers. In all the CPPs the duty for generation varies typically from ₹0.80 – ₹1.20 per unit. In this current scenario it is about ₹0.80 per Unit of kVAh. Since the power factor can be maintained with the Active VAr Generator, the captive generators can be

[3] The generator in the plant maintains the variation of import/export at the Grid at ±500kW, on an average. However, due to drastic variations in the system, the same can go as high as ±2000kW. Thus the daily average power consumption comes to the range of 10,000-20,000 Units.

operated at PF 0.99 to Unity. This is required to reduce the kVAh output of the generator. Prior to PF compensation, these generators were operated at a PF of 0.93 to 0.94 in order to maintain the required kVAr in the Grid. This is a notable achievement by the intelligent centralized additional cloud-based controller available in the active VAr generator design in order to control various parameters as per the earlier explanations.

Savings in Generation Duty = CPP kW × (1/ PF without AVG – 1/ PF with AVG) × Generation Duty× 24 × 365
= 36,000 × (1/0.94 – 1/0.99) × 24 × 365 × 0.80
= ₹ 13,555,126/- (3)

Finally the total annual savings for maintaining unity power factor at zero/close to zero loading conditions shall be calculated by addition of the results (1), (2) & (3)

$$\text{Total Savings} = (1) + (2) + (3)$$
$$= 18{,}524{,}436 + 45{,}552{,}000 + 13{,}555{,}126$$

Annual savings by intelligent AVG system = ₹77,631,562 (Approximately USD 1,200,000/- with an investment less than USD 120,000/-).

V. Conclusion

In simple terms, power factor compensation for such conditions of low load during floating operation of the CPPs in the cement/steel plants is not only reactive power compensation. It requires equipment with capabilities beyond reactive power. The equipment capacity installed in comparison with the plant capacity in kVA is negligible. However, the solution to which it caters i.e., unity power factor at floating load conditions, requires intelligent operating features and complete centralized plant control with a single controller of the active VAr generator. This is what makes this challenge stand out in the stage of power quality, where the plant is an orchestra and the active VAr generator, its conductor, and together they make symphony, unity power factor.

References

[1] Shvedov, G. V., Chorshanbiev, S. R., Shvetsova, E. V., & Nazirov, K. B. (2018, January). “Impact of solar generation connected to 0.4 kV grid on the power losses and the shape factor of load curve,”. Young Researchers in Electrical and Electronic Engineering (EIConRus), 2018 IEEE Conference of Russian (pp. 773-777). IEEE.

[2] Alberts, J. A., & De Kock, J. A. (2017, April). “Impact on power factor by small scale renewable energy generation,”. Domestic Use of Energy (DUE), 2017 International Conference on (pp. 146-151). IEEE.

[3] Liao, Yi-Hung, and Zheng-Jie Dai. "Two-switch three-phase LLC resonant circuit with power factor correction for microscale wind power generation system." Industrial Electronics for Sustainable Energy Systems (IESES), IEEE International Conference on. IEEE, 2018.

[4] Zhou, K., Yang, Y., Blaabjerg, F., & Wang, D. (2015). “Optimal selective harmonic control for power harmonics mitigation”,. IEEE Transactions on Industrial Electronics,62(2), 1220-1230.

[5] Grasso, Francesco, Antonio Luchetta, Stefano Manetti, Stefano De Giorgis, Franco Cenghialta, and Ernesto D'Antuono. "Improving power quality and efficiency in electrical plants using a three-phase series hybrid passive filter," AEIT International Annual Conference (AEIT), pp. 1-5. IEEE, 2016.

[6] Mahesh M. Rathore, “Thermal Engineering”, Tata McGraw-Hill Education Pvt. Ltd., 2010.

[7] Swapan Basu, Ajay Debnath, “Power Plant Instrumentation and Control Handbook: A Guide to Thermal Power Plants”, Academic Press, 2014

[8] Allen J. Wood, Bruce F. Wollenberg, Gerald B. Sheblé, “Power Generation, Operation, and Control”, John Wiley & Sons, 2012

[9] Guneet Bedi, Ganesh Kumar Venayagamoorthy, Rajendra Singh, Richard R. Brooks, Kuang-Ching Wang, “Review of Internet of Things (IoT) in Electric Power and Energy Systems” IEEE Internet of Things Journal, 2018

[10] K. Krishnaswamy, “Process Control”, Anshan Publishers, 2009

[11] Hirofumi Akagi, Edson Hirokazu Watanabe, Mauricio Aredes, “Instantaneous Power Theory and Applications to Power Conditioning”, IEEE Press Series on Power Engineering, John Wiley & Sons, 2017

[12] Srinivasarao Kamala, B. Dastagiri Reddy, Binita Sen, Sanjib K. Panda, Gehan Amaratunga “Improvement of Power Quality and Reliability in the Distribution System of Petrochemical Plants using Active Power Filters,” Industrial Technology (ICIT), Lyon, France 2018 IEEE International Conference

[13] J. Wang and R. Hamilton, "A review of negative sequence current," 2010 63rd Annual Conference for Protective Relay Engineers, College Station, TX, 2010

[14] Vigna K Ramachandaramurthy, “An Improved Dynamic Voltage Restorer For Power Quality Improvement,” International Journal Of Electrical Power And Energy Systems; March 2016, Volume :82

[15] Vigna K Ramachandaramurthy, “Assessment And Mitigation Of Power Quality Problems For Puspati Triga Reactor (Rtp),” Advancing Nuclear Science And Engineering For Sustainable Nuclear Energy Knowledge: Proceedings Of The International Nuclear Science, Technology And Engineering Conference 2016

[16] Arun Shankar VK, Umashankar Subramaniam, P. Sajeevikumar, Lucian MIHET-POPA, Viliam Fedak, Vigna K Ramachandaramurthy “Power Quality Performance Analysis of grid tied PV fed Parallel Pumping System under Normal and Vibrating Condition,” 2017, Energy Procedia

[17] Ann Jerin, Rini, Kaliannan, Palanisamy, Subramaniam, Umashankar, Thirumoorthy, Ad. “Power quality improvement of grid connected wind farms through voltage restoration using dynamic voltage restorer,” 2016, International Journal of Renewable Energy Research. 6. 53-60.