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Preparation Optimal Economic Solution with UPFC, for a Large Size Industrial Plant

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Abstract- **The Flexible Alternating Current Transmission System (FACTS) devices have opened new doors for controlling the power flow over the transmission line and to enhance the usable capacity of an existing power system. Unified Power Flow Controller (UPFC) is a versatile device which can independently control the line voltage and active and reactive power flow on the transmission line. This research shows that a UPFC is able to control both the transmitted real power and, independently, the reactive power flows at the sending and the receiving end of the transmission line. The UPFC model is applied to an existing large size power plant, installed on a 132-kV transmission line. The main objectives are to control active and reactive power flow and to minimize the power losses thus improving the overall economics of the system. MATLAB/Simulink has been utilized for simulations. The results show a considerable saving in the operation of the plant.**

Index Terms— **Active and Reactive Power flow, Transmission Network, Unified Power Flow Controller, Voltage Source Converter.**

I. INTRODUCTION

The world has paid great attention towards minimizing the cost of energy and to ensure quality of power with minimum inefficiency in electricity production, transmission and its distribution particularly for the industrial purposes. Cement production is a high energy consuming process in terms of electricity and thermal energy. Energy consumption by a typical Cement Plant is estimated about 30% of the total production cost. Electrical equipment installed in Cement industries is mainly consist of induction motors, industrial pumps, crushers, industrial fans and compressors. These equipment's consumes different amount of power and in different form for their smooth operations. The power we received from grid is in high voltage and same is distributed among the installed electrical equipment as medium or low voltage as per equipment requirement with the help of step-down Transformers installed at different sections of the Cement Plant. These large number of electrical devices and their power consumption makes a major cost factor for cement production. As, most of the Cement Plant load consist of motors and Transformers and these loads are inductive in nature and their presence make the network overloaded and thus result in voltage instability due to imbalance of the reactive power in the network and lower values of power factor [1].

Low power factor not only overload the electrical network but also make the installed equipment inefficient with an increase in the rating of Transformers, switchgears and cable cross sectional areas to meet the same load demands with an additional increase in cable losses and line current drawn by the network. To overcome these issues of Power Factor and voltage stability different FACTS devices are being used [2]. Most promising device known as UPFC because of its capability to provide excellent power flow control, voltage stability and voltage regulation. UPFC can work as STATCOM or SSSC when the DC link switch between two voltage source converters of the UPFC is open and work as UPFC when the switch of the DC link is closed [5].

The research investigates the suitability of a UPFC for decreasing the power loss as well as alleviating the problems of voltage instability. The technical and economic benefits obtained by power factor improvement are discussed in detail. A simulation model was developed in Simulink for a real existing cement plant of about 32 MW size.

II. PRINCIPLES OF UNIFIED POWER FLOW

A. OPERATING PRINCIPAL OF UPFC

Dr. L. Gyugyi proposed the UPFC in 1991 [1], [2]. Unified Power Flo Controller having two voltage source converters which are linked through a common DC link via a switch.one converter is connected in series with the line through a transformer. Second converter is connected in shunt with the line with another transformer. The schematic is shown in the Fig. 1. If the DC common link switch is open it acts as STATCOM or SSSC. If the switch is closed it acts as UPFC.UPFC has unique characteristics to control the all line parameters. The Active and Reactive power can also be controlled. The control of Active power is without changing the reactive power. The Series converter can control the reactive power by injecting a voltage in series with the line which is in quadrature to the line current.

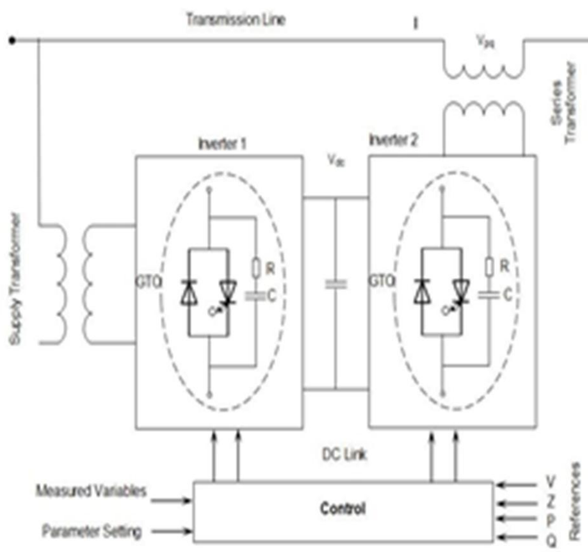

FIGURE 1. UPFC schematic.

Whereas the active power is controlled by the series converter by injecting a voltage in line which is in phase with the line current. The main function of the shunt converter is to supply/absorb the active power demand by the series converter which appears on the DC common bus. Shunt converter can also control the reactive power [8]. The Active and Reactive Power relations are described in equation 1 and 2.

$$P = \frac{VsVr}{X} Sin\alpha \tag{1}$$

$$Q = \frac{Vs(Vs - Vr)}{X} Cos\alpha \tag{2}$$

It is clear from the above relation that active power is dependent on the power angle whereas reactive power is dependent on the difference of the voltages of sending end and receiving end. In order to control the voltage regulation and active power flow the UPFC series converter will inject a voltage of any magnitude and desired phase angle to control the flow of power on the transmission line where as the shunt converter will regulate the bus voltage to which it is connected.

B. UPFC CONTROL SCHEMES

UPFC can act as STATCOM and SSSC if the DC common link switch is open. The control schemes of both STATCOM and SSC are explained below [9].

a) SERIES CONVERTER

The mode of operation of the series converter is in automatic power flow and the injected voltage by the series converter is determined by the closed loop control for desired power. The reference values of the active and reactive power (P_{ref}, Q_{ref}) are compared d with the P_m and Q_m of the line. The difference of these values as error send to the PI Controller for the generation of V_d and V_q. The below equations can be used for the calculation of magnitude of V_{pq} and α [11].

$$V_{pq} = \sqrt{(V_d^2 + V_q^2} \tag{3}$$

$$\alpha = tan^{-1}\left(\frac{V_q}{V_d}\right) \tag{4}$$

With these values of Vdq and α Space Vector Pulse Width Modulation (SV-PWM) pulse generator generates pulses for Series Converter to ensure desire power flow in the line. Series Converter control is shown in Fig. 2.

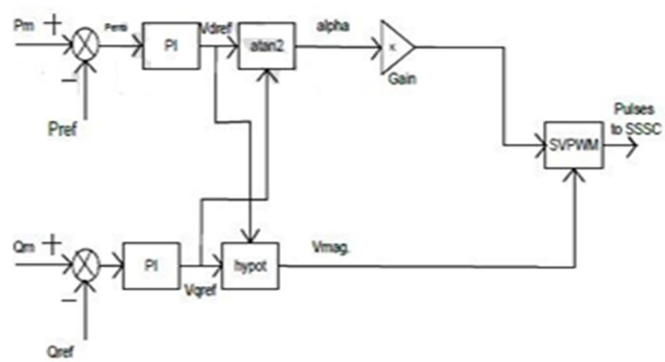

FIGURE 2. Series converter control.

b) SHUNT CONVERTER

The mode of operation of the shunt converter is Voltage Regulation. The control strategy is shown in Fig. 3. This control scheme is used for directing the reactive power absorb/generate by Voltage source converter. The phase locked loop (PLL) provide the reference angle. The real Id and reactive Iq parts of the current are calculated. The value of Vd is compare with the reference value of the shunt voltage Vshref. PI Controller received the error and it generate the reactive component of current Iqref [12]. The real part of Idref is calculated by comparing the voltage Vdref and DC Capacitor voltage Vdcm. The measured values of real and reactive components of currents are compare and the error is sent to PI Controller for the generation of Vd and Vq. Moreover, Vdq and are calculated by equation 2 and 3. With these values of Vpq and α Space Vector Pulse Width Modulation (SV-PWM) pulse generator generates pulses for Shunt Converter to ensure voltage regulation [13].

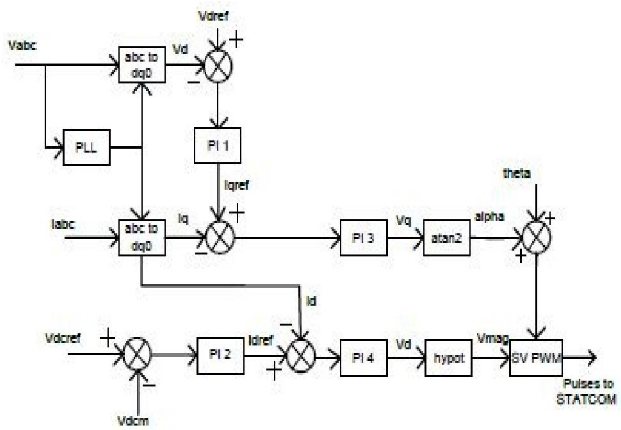

FIGURE 3. Shunt converter control.

III. TEST SYSTEM

DG Cement Plant is governed by 132 kV grid transmission lines and its power consumption is nearly 30 MW. Three sections of Plant have more distortion in the power system are, Kiln section having a total load 9600 kW, Raw Mill section having a load of 9400 kW and Cement Mill section which has a total of 2500 kW. As, most of the equipment installed in the Cement plant is consist of motors, Transformer which are inductive load in nature. These loads absorb the additional inductive reactive currents and consequence of these currents is such that it makes the system inefficient and result in low power factor of the system.

Furthermore, these inductive loads in the DG Cement Plant is an important component of the total system load that contributes to the Voltage instability. These are fast restoring loads (in the time frame of seconds) and requires high reactive powers. Due to the reactive power requirements by these loads and its presence at the end of the lines an imbalance is created in the system which is a major reason of voltage stability issue in the DG Cement plant.

TABLE I
LOAD DETAILS OF THE PLANT

Section	Total Load
Kiln	9600 kW
Raw Mill	9400 kW
Cement Mill 1	5250 kW
Cement Mill 2	5750 kW
Miscellaneous Load	2000 kW
Total Load	32 MW

A. MATLAB/SIMULINK MODEL

The UPFC is used to control the active and reactive power flow over the 132-kV transmission line. The Cement Plant under this study, is connected in a loop configuration and consist of five buses (B1-B5) which are interconnected with each other through three transmission lines TL1, TL2 and TL3 as shown in Fig. 4. A step-down Transformer of 34 MVA is connected between B4 and B5.

UPFC installed with the system will control the active and reactive power flow control with the help of the series converter by injecting a voltage of desire magnitude and phase angle to maintain the desire power flow over the line. The voltage regulation is achieved through shunt converter to overcome the issue of voltage instability of the system. The rating of the Series Converter is 1MVA and maximum injection is 10% of the nominal line to ground voltage in series by this converter. The DC Capacitor link value is set to 750 µF and DC link nominal voltage are set to 40kV.The Series Converter is set to operate in Power Flow Control Mode. The rating of the Shunt Converter is 1MVA and the rate of change of reference voltage is set to 0.1pu. The Shunt Converter is set to operate in Voltage Regulation Mode.

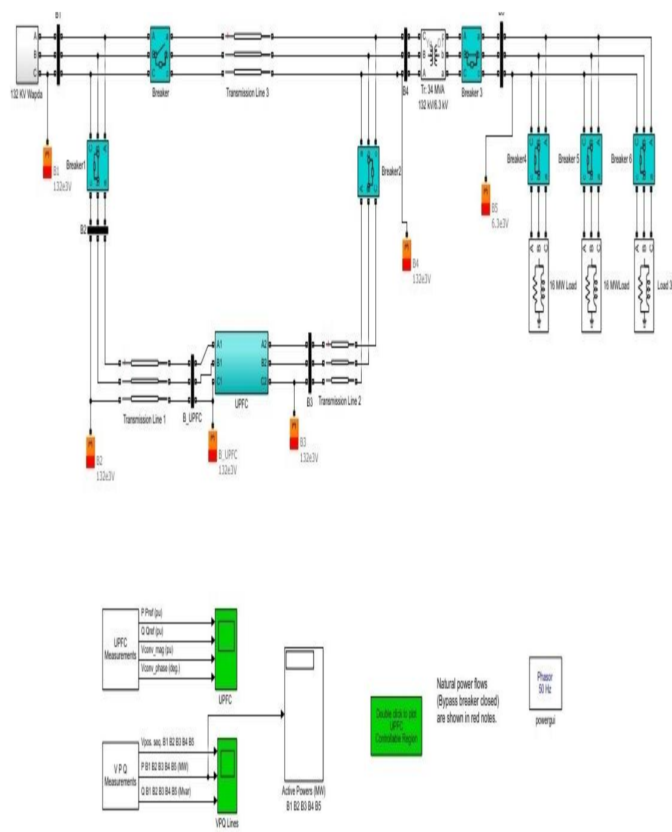

FIGURE 4. MATLAB /Simulink model of DG cement plant.

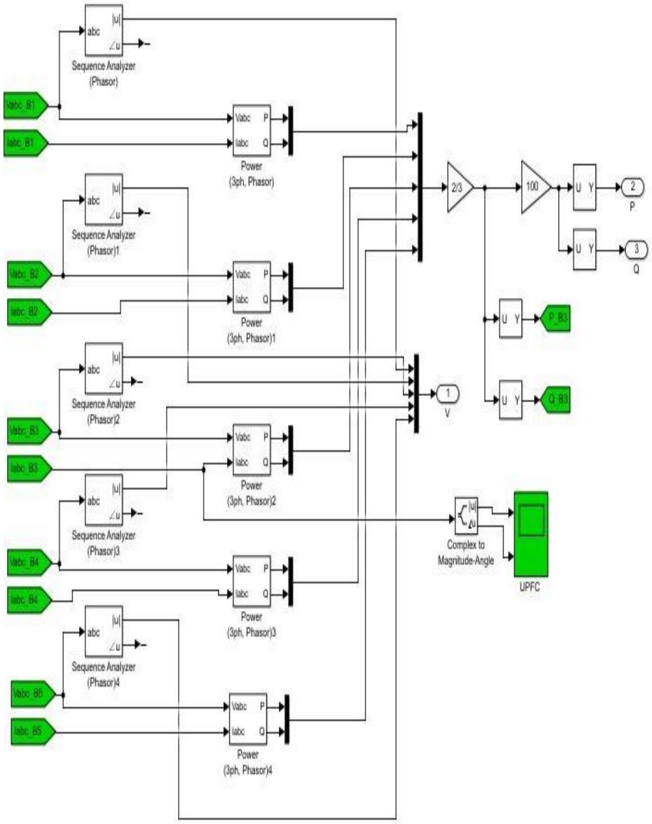

FIGURE 5. P and Q measurement block.

IV. SIMULATION RESULTS

The behavior of the plant is observed for 20 seconds. From 0 -10 sec power system is run in normal condition and UPFC is remain in bypass mode and after 10 sec UPFC model synchronizes with the system and start its working. The results are shown in Fig. 7.

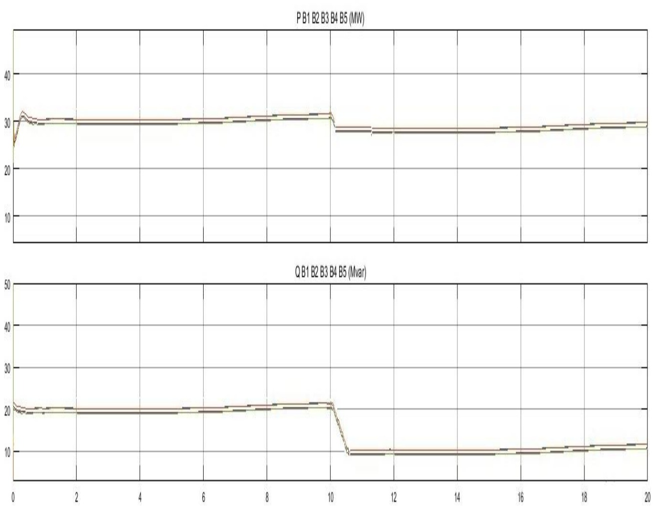

FIGURE 6. P and Q simulation results.

TABLE II
VOLATGE, P AND Q WITH AND WITHOUT UPFC

Bus No.	Bus Voltage without UPFC	Bus Voltage with UPFC	Bus Power without UPFC		Bus Power with UPFC	
	Voltage (Pu)	Voltage (pu)	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1	0.9966	0.9967	30	19.37	28.65	10.40
2	0.9993	1.0020	29.9	19.32	28.55	10.35
3	0.9996	1.0010	29.8	19.26	28.45	10.30
4	0.9926	0.9942	29.7	19.19	28.35	10.29
5	0.9978	0.9978	29.6	19.12	28.25	10.24

From the simulation results as shown in the tables it can be evaluated that that the power factor corrected from 0.84 to 0.94. Furthermore, the reactive power is reduced by 46% and apparent power is reduced by 14%. The value of Active Power reduced is due to the decrease in power losses which are due to power factor improvement of the system.

The reduction in value of reactive value also benefits in terms of less rating of cables, transformers, switchgears and other equipment. Furthermore, the imbalance of the reactive power in the system is improved which results in voltage stability of the system.

The response of voltage variation after using the UPFC. The simulation results show that a voltage of 0.1 pu is injected at an angle of 135 degrees to improve the power factor from 0.84 to 0.94 to meet the acceptable range of WAPDA/NTDC.

V. ELETRICITY SAVINGS

UPFC device has been placed in the power system of DG cement plant. Overall desirable results have been achieved. It is important to carry out the cost benefit analysis to ensure its feasibility in the Cement Plant to get maximum benefits in terms of cost saving. It is important to know here that other total load of this plant for WAPDA is considered to be approximately 30 MW. Keeping in view the electricity consumption of the plant from IESCO (Grid) from 2017- 2018, details are given below:

Power Consumption without UPFC = 30 MW
Total Power Consumed using UPFC = 28.65 MW
Total Power Saved = 1.35 MW
Total Amount of Energy saved per annum = (Power saved) x (hours/day) x (days/ year)
= 1.35 MW x 24 x 365
= 11,826,000 kWh
Flat Rate = 20 Rs/ kWh (Average cost per unit)
Total Amount saved (Rs) = (energy saved/year) x (flat rate)
= 11,826,000 x 20
= **236,520,000 PKR**

VI. BREAKEVEN PERIOD

Cost of Series and Shunt Controller for UPFC = $300/kVar
Total Power Saved by installing UPFC = 10 MVar
Cost of Controllers on DG Cement Plant = 300 x 10,000 kVar
= $ 3,000,000
Conversion of USD to PKR: $1 = 155 Rs.
Cost of UPFC in PKR = 3,000,000x 155
= **465,000,000 PKR**.

The cost of controllers is high initially. However, in 2 years, the power consumption can be done to the point that the industry can payback the cost of the controller. The installation and maintenance charges will approximately lead to a breakeven period of 4-5 years.

VII. CONCLUSIONS

UPFC device simulated on electrical system has shown quite good result for suitability as an optimal solution for large industrial plants to ensure voltage stability, reduction in power losses and improvement in the overall power factor of the system for efficient operations of the plant.

The series converter is in automatic power flow mode and shunt converter in voltage regulation mode is simulated. The results shown that fast response and effectiveness of UPFC in controlling active and reactive power flow and voltage regulation of the transmission line to which UPFC is connected with the help of PI Controller based control scheme.

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