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Design of 2500 KVA 11/0.4 KV Distribution Substation Based on Load Flow Analysis Using ETAP Software

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ABSTRACT

For the development and growth of economy and social condition of any country, constant supply of good quality electrical power is essential. The main barrier to achieving this goal is the variation of voltage in the network. The load connected in a system varies with time, which causes the variation in the bus voltages. By properly designing and installing the substation, these voltage regulations can be reduced. Load flow analysis provides the steady-state characteristic data and generates reports for voltage magnitude, phase angle, the flow of active and reactive power, losses in the system, etc. Accurate and highly reliable results of Load Flow Analysis (LFA) can be obtained by using ETAP (Electrical Transient Analyzer Program) software. In this research, ETAP software, which utilizes the Adaptive Newton-Raphson method, has been used for performing the load flow analysis of 2500 KVA 11 /.4 KV substation. Actual manufacturer data is utilized for transformers, VCBs, circuit breakers, cables, and other components, whereas computed data is used for loads on the system. The main focus of this study is to improve the voltage regulation and the overall power factor (PF) of the network by inserting capacitor bank also known as the PFI plant in the system. This technique also minimizes the input current and power losses.

Keywords: Load flow analysis, One line diagram, ETAP, PFI, Single line diagram, and Distribution substation.

INTRODUCTION:

Substation plays an important role among generation, transmission and distribution system. Electrical power that flows through several substations may be at different voltage levels from generation to consumers end in a network. A substation's primary function is to transform voltage levels from high to low and vice versa keeping constant power flow. It works like a hub in the power system among the electrical generation plants, transmission lines and distribution system. Distribution system consists of several components, that work together to transfer and distribute power to the end users. End users consume electrical energy in the form of current through electrical loads. These electrical loads, which can be categorized as resistive, capacitive and inductive loads, are generally referred to linear and non-linear loads. Linear loads only consume electrical energy whereas non-linear loads also generate energy and create power factor problem by returning the energy to the source in a network (Witherden *et al.,* 2010).

A proper design approach is vital for ensuring reliability and quality of power supply, keeping the voltage and frequency fixed while satisfying the demand. These conditions can be achieved by load flow studies performed utilizing dedicated computer aided programs (Pai, 2014). Various factors like maintainability, simplicity of operation, safety, economy, international code, recommended practices and standards must be taken into consideration in the design phase (Kezunovic *et al.,* 2010). Location of the proposed substation, single line diagram, full details of electrical equipment to be installed, layouts ofequipmentandprovisionformeteringunits, arrangement for voltage regulation, and power factor improvement (PFI) plant should also be considered.

Load Flow Analysis

Load flow study is the best approach to find out the voltage, current, power at any point under normal or fault conditions in a system. The available tools for load flow analysis are Newton-based load flow solution, conventional Newton method, Newton-Raphson method, Fast Decoupled method, Gauss- Seidel method, etc (Stott, 1974; Stott & Alsac, 1974). Load flow analysis provides information about power generation, delivery, losses occurred in the network, branch current, voltage on buses, active, reactive and apparent power, etc (Katira and Porate, 2009). Load flow analysis reports are also required for operating the existing system satisfactorily and for the future expansion of the network (Ademola & kareem, 2014).

Power Flow Analysis using ETAP Software

ETAP is an analyzer program containing documenttation elements and task-oriented program modules, which uses the Newton-Raphson method for analyzing the load flow. ETAP is faster than real-time and gives accurate, precise, and reliable outcomes (Baby & Sreekumar, 2017). The analysis provides steady-state characteristic data of active power, reactive power, voltage magnitude, voltage phase angles, system losses, and power consumption (Hasan *et al*., 2020; Shahriari *et al.,* 2012).

ETAP monitors the system network ac- curately and generates a detailed and organized representation of the output result (Ijeoma & Olisa, 2019). The obtained results from the analysis help to check the system voltage profile, phase angles, trans- former loadings, system losses, and contribution of our optimization technique (PFI plant) in system improvement.

Objectives

The main objective of this paper is designing and simulating 2500KVA 11/.04 kV substation and analyzing the output data using Load Flow Result Analyzer, overcoming the voltage regulation problem, and improving the power factor for an optimal, safe, and reliable power system.

METHODOLOGY:

For obtaining accurate results in ETAP, accurate and detailed parameters of electrical equipment are needed (Brown *et al.,* 1990). Here, we designed the model in ETAP inputting minimum parameters without sacrificing accuracy (Arockiya *et al.,* 2016).

For the non-availability of some parameters, we used typical values from ETAP Library. For Grid design rated power in KVA, rated voltage etc. are required. These values are essential for Grid design and are usually obtained from the power supplier. Generator rated power, voltage; PF, reactance, resistance, etc. are needed for modeling it accurately. This data can be derived from the manufacturer. Rated apparent power rated primary and secondary voltage, positive and zero sequence impedance with X/R ratio, earthing types, etc. are required for transformer modeling in ETAP. Connected load and largest motor to be started on the transformer characterized the rated apparent power of the transformer. Rated power of the motor, rated voltage, power factor, efficiency, inrush current, locked rotor current etc. are required for proper modeling of the Motor in ETAP. The largest motor to be started on the transformer dominates the system balancing. A group of low voltage loads merged into one load and modeled as a lumped load in a big system (Prabhu *et al.,* 2016).

The total power and power factor of a group are considered as the rated power and power factor of the lumped load.

One Line Diagram (OLD)

According to the calculated loads and demand, we have designed a stable and reliable system network that can supply the required power with satisfaction. When designing the substation, special care is taken in feeding the normal load from regular bus bars and essential loads from emergency bus bars. The single-phase loads are connected to any one phase and the neutral, and the three-phase loads are connected straight across the 3-phase lines.

Fig 1 represents the connection diagram of the substation, which consists of incoming or power feeder connection (11KV), 2500 KVA 11/0.4 KV dry type distribution transformer, outgoing feeder for feeding the switchgear (VCB), circuit breaker, buses, cables, and various loads.

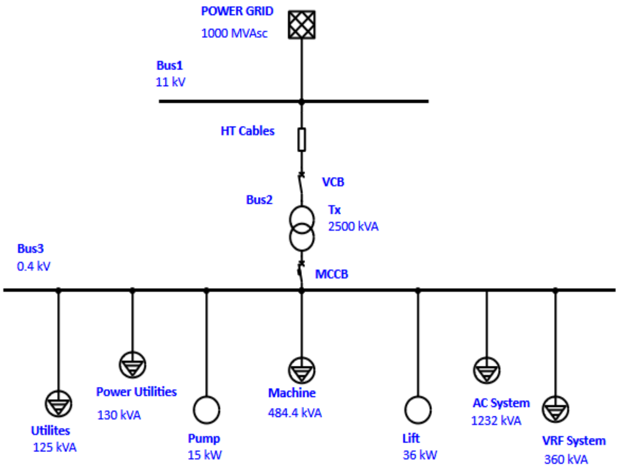


Fig 1: OLD before Application of PFI Plant.

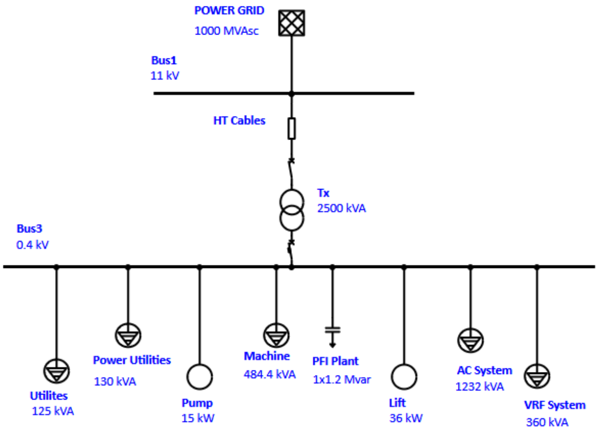


Fig 2: OLD after Application of PFI Plant.

Fig 2 represents the one-line diagram of the overall connection of the 2500 kVA distribution substation. For improving the standard of the overall network, we used capacitor bank otherwise called the PFI plant as an optimal technique (Bhattacharyya *et al.,* 2011). A significant improvement in voltage regulation was noticed after the insertion of the PFI plant.

Simulation of the Substation in ETAP

The one line diagram of 11/0.4 kV substation, shown in **Fig 1** and **Fig 2** have been considered for load flow analysis. The simulation was conducted using ETAP software for determining the power flow, system losses, power factor, and voltage profile of the total network. The PFI plant is connected to the load- bus side for optimal performance. The simulation reports of the network with and without PFI plant for different parameters are then compared.

RESULTS AND DISCUSSION:

Load flow simulations give us result on one-line diagram and generate tabulation reports of calculated bus voltage, its magnitude, angle, currents, and power flow through the electrical network etc. We analyzed the output data for different values of equipment by using ETAP Load Flow Result Analyzer, which presents data in a compact and summarized way (Chandan *et al.,* 2017).

Simulation before Application of PFI Plant

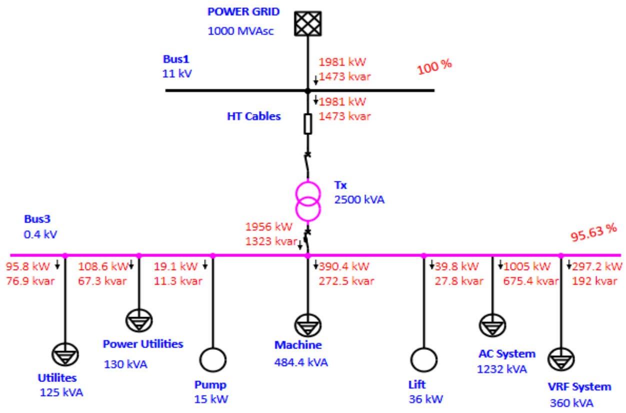


Fig 3: LFA before Application of PFI Plant.

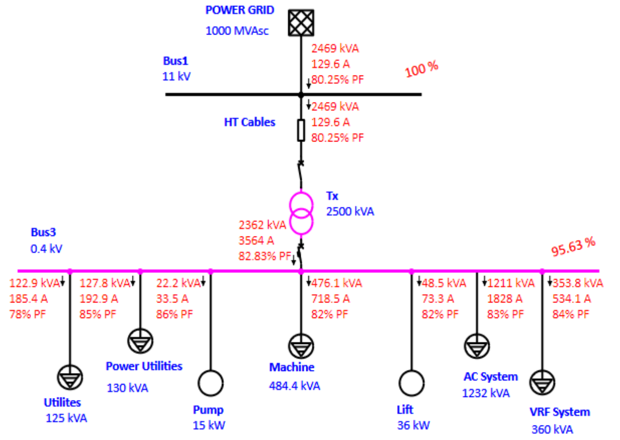


Fig 4: LFA before Application of PFI Plant.

Fig 3 & 4 shows the sub-stations one-line diagram before applying the PFI plant. By performing analysis using ETAP simulation, the result shows that the percentage (%) voltage regulation (drop) across the 2500 kVA transformer is 4.37, input power to the bus no. 03 is (1956+ j1323) kVA, and the total power factor is 82.83%, which accounts for the high power losses, and voltage drop.

Simulation after Application of PFI Plant

Fig 5 shows the load flow analysis after the injection of the capacitor bank into the network. The PFI plant consists of a total capacity of 1200 kVAR capacitors, which are in delta connection. After applying the capacitor bank, the system's voltage profile and power factor improved drastically, and total losses of the system reduced significantly. The power level to the network improved from (1956+ j1323) kVA to (1978 + j171.3) KVA.

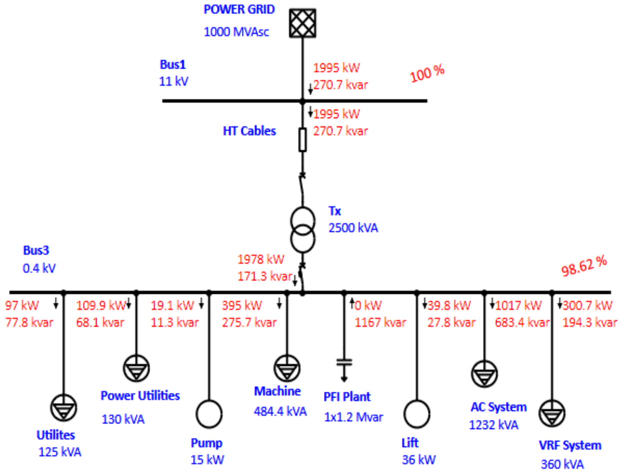


Fig 5: LFA after Application of PFI Plant.

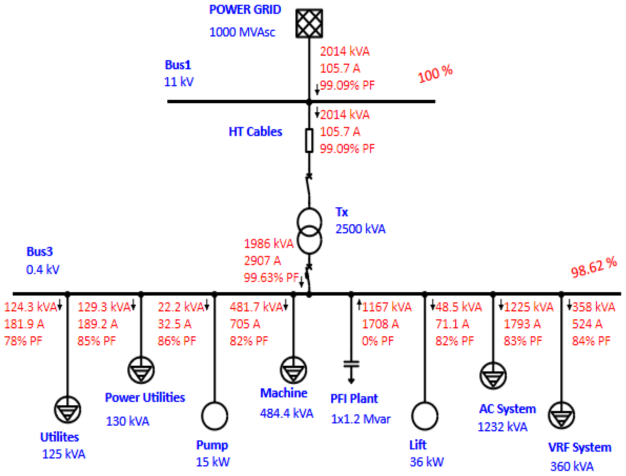


Fig 6: LFA after Application of PFI Plant.

The low power factor (82.83%) caused the bus to flag critical, which improved extrinsically to 99.63%. The bus voltage (%) was improved from 95.63 to 98. 62. Therefore it is obvious that the system's power factor and losses have improved dramatically. We also observed that the operating bus voltage (Bus 03) has increased significantly. The real power load supply was improved.

Table 1: Parameters with/without PFI Plant.

Parameter	Without PFI Plant	With PFI Plant
Power Loss in TX (KW)	25.1	16.7
Power Loss in TX (KVAR)	150.4	100
Voltage drop (%)	4.37	1.38
Power Factor (%)	82.83	99.63

Chart: 1

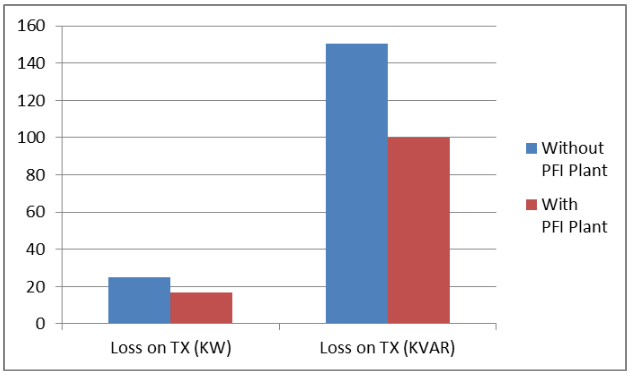
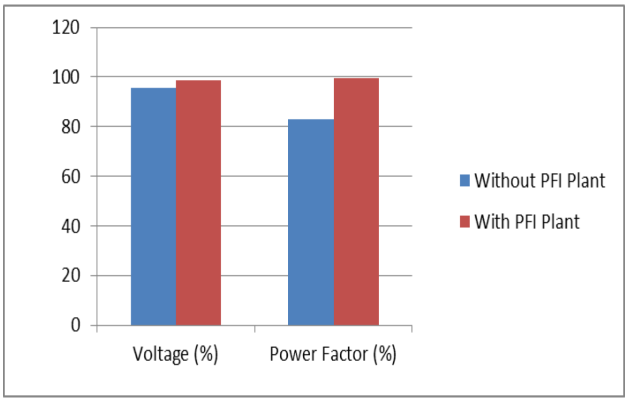
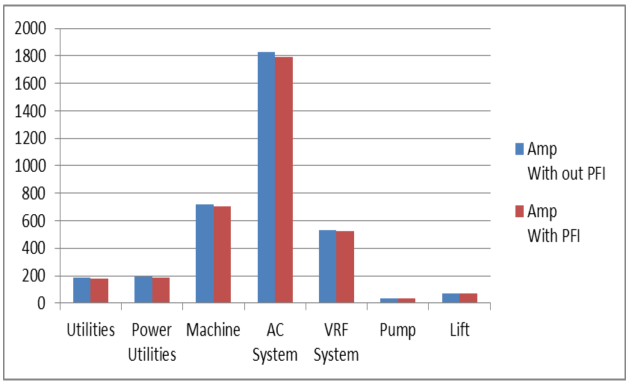


Chart: 2



From **Table 1** and **Chart 1 & 2**, we can observe that the indication of voltage regulation changes from critical situation to marginal condition but still lies in the under-voltage range. In addition, the losses on transformer have decreased.

Chart: 03



From **Chart 3**, we can conclude that current drawn by different loads have decreased after the insertion of the PFI plant, which allows using lower capacity circuit breakers and minimizes the insulation cost of high capacity cables and other equipment.

From the reports, it can be concluded that the voltage drops are within the permissible limit, and the system's overall power factor has improved. The transformer's specified capacity is perfect, and there is adequate provision to meet the future load demand.

CONCLUSION:

In this paper, we designed a 3-phase 2500 KVA 11/0.415 KV distribution substation, with the details of equipment parameters and simulated on ETAP software. The substation is simulated with and without the PFI plant, and the obtained results are analyzed and compared. The results suggest that implementation of the properly sized transformer, rightly sized and placement of PFI plant, properly rated circuit breakers and cables, etc. improve the power factor, reduce the reactive power consumption, and improve the active power.

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CONFLICTS OF INTEREST:

The authors declare that there is no conflict of interest to publish it.

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