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# Surveillance of Captive Generation Units unified with Solar Power Plants

**[1]N. Srilatha, [2]J. Sandeep**

[1]Department of Electrical Engineering, Osmania University, Hyderabad, India
[2]NRSC, Indian Space Research Organization, Hyderabad, India

***Abstract :*** Industrial loads and large power consumers make use of various forms of Renewable Energy Sources (RES) apart from the services of utility gris. This is done in order to reduce Running Maximum Demand (RMD) and to have financial savings with reduced consumption of energy from the grid. Solar Power Plant (SPP) based RES is the most abundant form and most widely used energy source. Captive generation units are also employed along with SPP based RES to cater to load requirements during grid failure. But the operation of captive units is badly affected as soon as SPP based RES start supporting the load, when the grid fails. This paper analyzes the impact of SPP based RES on Captive generation unit and proposes a protection scheme using local reactive power units.

***Index Terms* - Renewable Energy sources, Diesel Generator Set, Solar Power Plants, Captive Generation.**

## I. INTRODUCTION

In an integrated distribution system, which comprises of solar power plant, grid and captive generation, flow of active & reactive powers is an important concern. When the solar is integrated with the utility grid, reactive power drawn from grid is almost constant. However, the active power demand is reduced as the RES supplies maximum active power to the load. These RES when integrated with the captive generation during grid failure, impacts severely the power being drawn from the captive source [1, 2]. The amount of reactive power produced by generators must closely match with that being consumed, as most of the synchronous generators are defined by their power factor limits [3, 4 , 5].

This paper addresses a typical problem of power system failure in an organization consisting of RES integrated with the grid and a captive generation unit i.e., Diesel Generator (DG) unit to support the load during grid failure with a defined power factor limit of 0.8. The DG has undergone a mechanical failure and lead to power failure when RES has been operated along with DG during grid failure. A strategy is proposed to protect this captive generation unit from outage by load variation and employing local reactive power units. MATLAB 2016b software environment was used to simulate the problem at a reduced scale by integrating 100kWp Solar Power Plant (SPP) with grid, captive generation unit (DG) and variable loads with capacitor banks to analyze the active and reactive power flow, source power factor.

## II. ENERGY CONSUMPTION TRENDS

The SPPs are installed in the organization to cater to emergency energy demand in various phases. Fig. 1 indicates the strategy implemented in commissioning of SPPs in the organization to mitigate the energy demand of the utility and saving of the energy charges in the utility bills [6, 7, 8].

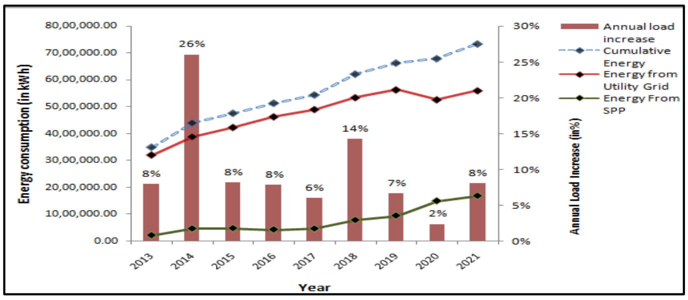


Fig.1 Various Energy and load Trends, SPV installation from 2013 to 2021

The increase in energy consumption has increased impact of RMD severely on grid & DG during this period as shown in Fig.2. RMD observed during year 2013 was 650kVA and it has increased up to 1050 kVA in 2021.

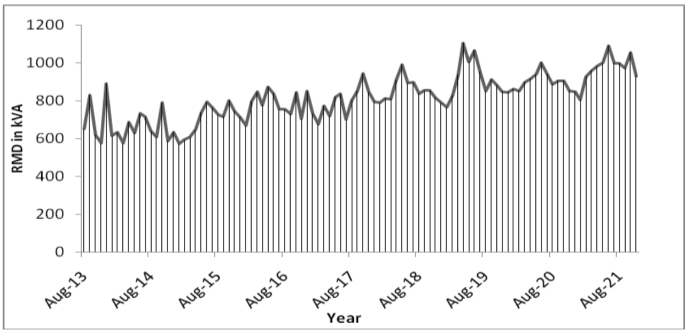


Fig. 2 Running Maximum Demand (RMD) from 2013 to 2021

## III. Problem Statement

To analyze the source of the problem the survey of the major systems was done which support the distribution system in organization. It is understood that the entire loads and plants are distributed in two segments in parallel and are supported by running and standby systems equally. The initialization sequence of loads is detailed in Table 1.

Table 1 Load Initialization on Distribution System

| Sl. No. | Description of the system | Initialization Sequence |
|---|---|---|
| 1 | Lighting load (minor load) | Immediately |
| 2 | UPS and server loads (Moderate load) | Immediately |
| 3 | Air Conditioning load (Major load) | After 3 min. |
| 4 | DG sets support to load during grid failure | Within 30 Sec. |
| 5 | Start of Solar Power Plants | 45 Sec. |

The active power demand on grid during the peak hours reduced to 10% and the reactive power demand of the inductive load was mitigated with capacitor banks. Fig. 3 shows active and reactive power demand curve of a typical sunny day.

Initially the SPP is integrated with grid and feeds power to the loads. At the instant of grid failure, SPP gets disconnected from load. Captive generation units i.e., DG sets start and feed power to loads. Depending on the connection sequence of various components, active and reactive power demand on the system is minimal initially as the air conditioning loads (major active and reactive load) are not started by then.

The active power from the DG feeds most of the lighting and UPS loads initially and thus less active power demand is observed on DG sets. But since the air conditioning loads pick up after 3 min., most of the active power demand is catered by SPP that has commenced after DGs are started. Therefore, the reactive power demand on the DG set increases to a very high value. This condition reduces power factor of DG set below operational range i.e., to 0.6 and voltage drops drastically. This large unbalance in active and reactive power demand causes pressure on the DG shaft, causes failure of gear assembly, AVR and isolation transformer.

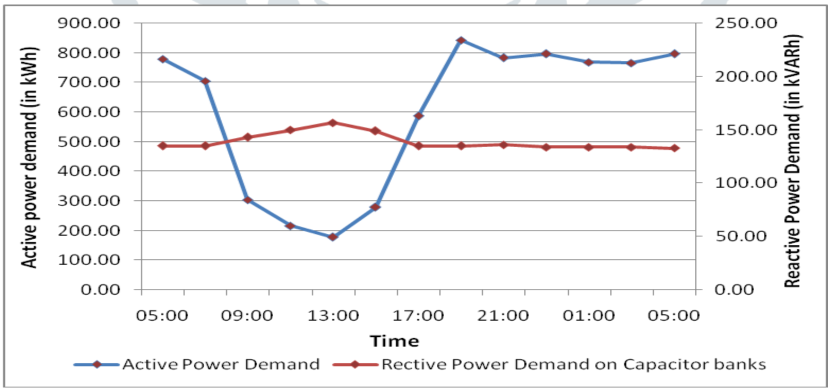


Fig. 3 Active and reactive power demand curve

## IV. Methodology For Protection of Captive Generation unit

The methodology adopted for protection of captive generation unit in presence of RES is to monitor the power factor of the DG and maintain the value within permissible range under all operating conditions. The task of maintaining the power factor has been implemented through employing capacitor banks [5, 9]. The details of the monitoring and protection of DG is presented in block diagram as shown in Fig. 4. A scaled down model of the organization is simulated in MATLAB [10, 11] using a 100kWp SPP in presence of variable load environment as indicated in Fig 5. The distribution system consists of RES [12, 13], captive power source, grid, and capacitor banks. The variable load represents the industrial load.

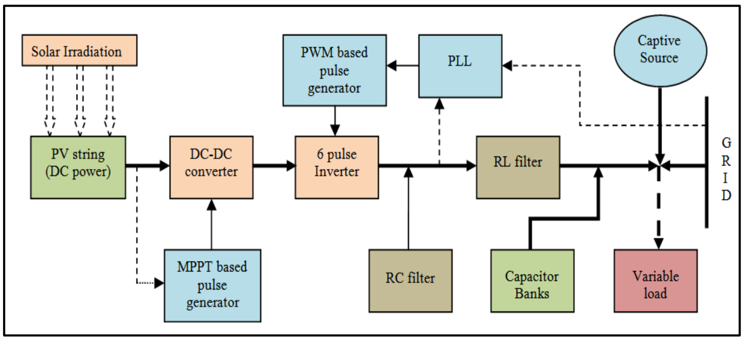


Fig. 4. Block Diagram of the Simulation setup

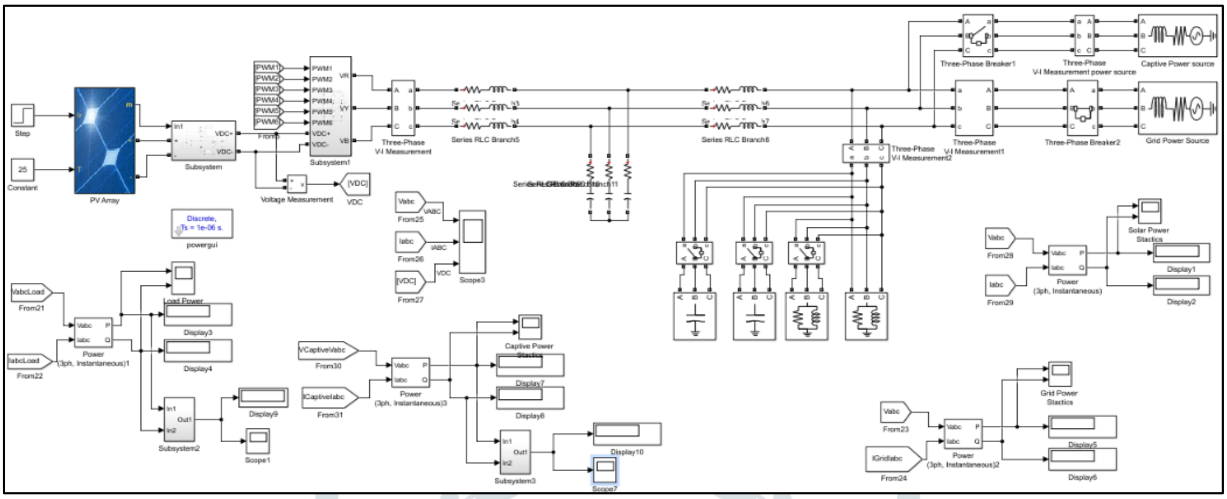

Fig. 5 Problem formulation in MATLAB for protection and control of captive power source

## V. Results and Analysis

The results are analyzed with respect to the performance of SPP. When 100kWp SPP is connected to Load 1(100kW, 10kVAr fixed load), 100kW, 75kVAr captive power source, grid, Load 2(20kW, 10kVAr variable load) and two capacitor banks (10 & 5 kVAr), it is observed that SPP supplies maximum active power to the load, and minimal active power is drawn from grid as depicted in Fig.6. It supplies very minimal reactive power to the load and draws maximum reactive power from grid.

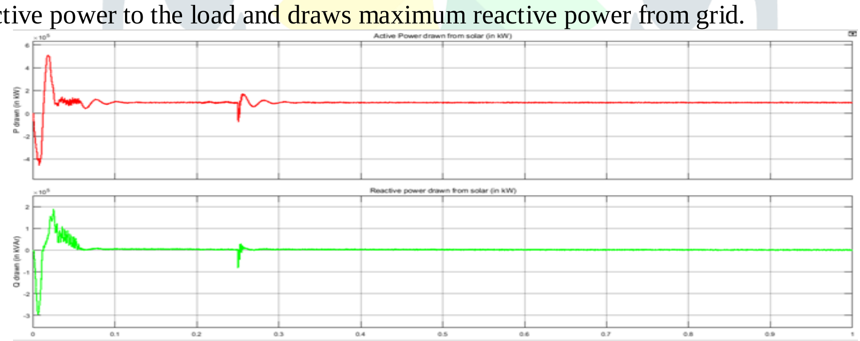

Fig. 6 P & Q output of SPP during integration with grid, captive generation, and variable loads

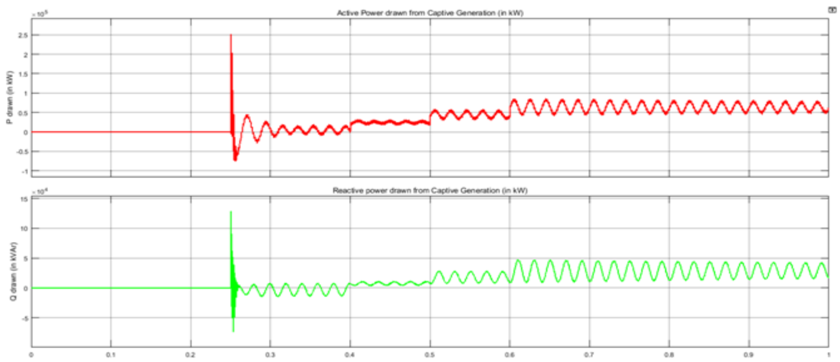

Fig. 7 P & Q generation from Captive unit from 0.25 seconds after grid failure at 0.2 seconds

At 0.2 sec grid gets disconnected and captive generation unit is switched on at 0.25 sec. At this moment maximum reactive power is drawn from captive power source and maximum active power is drawn from solar power plant.

Now at 0.4 sec., load 2 added in the system. As the SPP is of 100kWp the entire active and reactive power demand of load 2 is transferred to the captive power source. Subsequently, at 0.5 sec a capacitor bank of 10 kVAr is added in the system and the reactive power demand on the captive power source is dropped from 10kVAr to 3.50 kVAr. Another capacitor bank of 5kVAr is added in system at 0.6 sec and the reactive power demand is further reduced. The load power factor is approximately 0.98 initially and gets reduced to near 0.96 when load is added in the system at 0.4 sec. The power factor is improved when capacitor bank is added at 0.5 sec and 0.6 sec to 0.98 and 0.99 respectively.

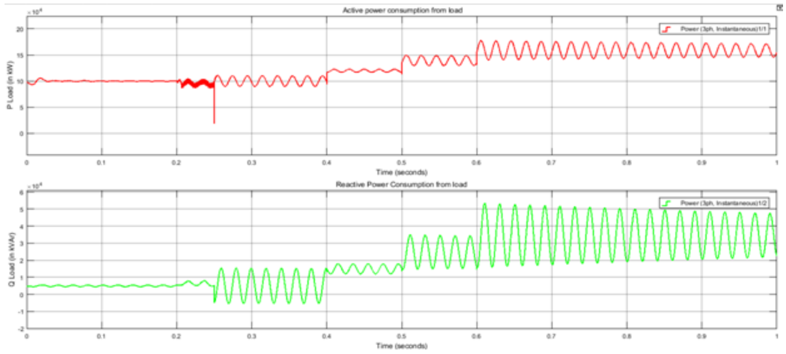

Fig. 8 Active & Reactive Power demand from Load after grid failure

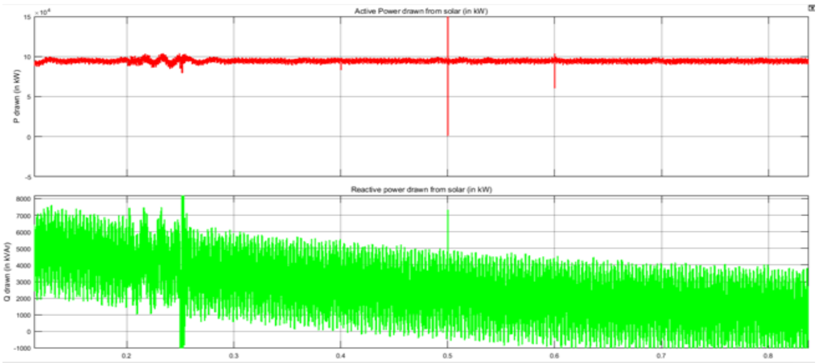

Fig. 9 P & Q generation from Solar power during grid failure

Table 2 PV Characteristics With Captive Generation, Variable Loads And Capacitor Banks

| Sl. No. | Description | Switching Time (s) | Active Power Consumed | Reactive Power Consumed | Active Power Generated | Reactive Power Generated | Remarks |
|---|---|---|---|---|---|---|---|
| **Grid power (off @ 0.2 Sec.)** | | | | | | | |
| 1 | Load 1 | Initial | 100 | 10 | 7.20 | 2.70 | The grid shares minimal P&Q power initially due to filters circuit. Grid is off at 0.2 Sec. |
| 2 | Load 2 | 0.4 | 20 | 10 | 0 | 0 | |
| 3 | Cap. -1 | 0.5 | 0 | 10 | 0 | 0 | |
| 4 | Cap.-2 | 0.6 | 0 | 20 | 0 | 0 | |
| **Captive power (starts @ 0.25 Sec.)** | | | | | | | |
| 1 | Load 1 | 0.25 | 100 | 10 | 0 | 2.40 | The grid shares minimal P&Q power initially due to filters circuit. Cap. Gen. starts at 0.25 Sec. |
| 2 | Load 2 | 0.4 | 20 | 10 | 23.00 | 10.00 | |
| 3 | Cap. -1 | 0.5 | 0 | 10 | 23.00 | 3.50 | |
| 4 | Cap.-2 | 0.6 | 0 | 20 | 23.00 | 2.00 | |

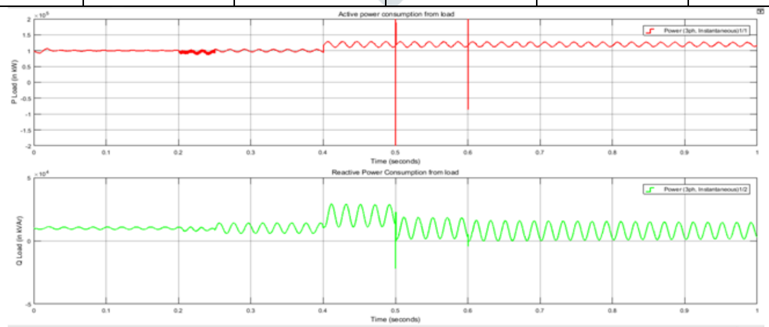

Fig. 10 Load consumption during grid failure with reactive power support

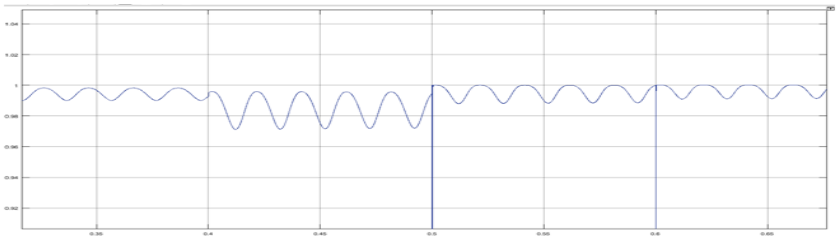

Fig. 11 Load Power Factor Characteristics with reactive power support during grid failure

Subsequently, another capacitor bank is added on the system at 0.6 sec which has further reduced the reactive power demand on the system and power factor of the captive power source is improved to 0.99.

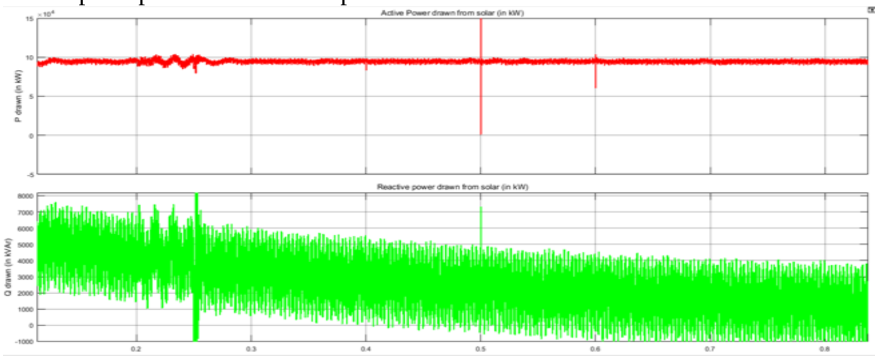


Fig. 12 P & Q generation from Solar power during grid failure

Now, 0.4 Sec. 20kW, 10kVAr load added in the system. As the SPP is of 100kWp the entire 20kW, 10kVAr active and reactive power demand of load is transferred to the captive power source. Subsequently, at 0.5 Sec a capacitor bank of 10 kVAr added in the system and the reactive power demand on the captive power source is dropped from 10kVAr to 3.50 kVAr. Another capacitor bank of 5kVAr is added in system at 0.6 Sec and the reactive power demand is further reduced. The load power factor is approx 0.98 at initial and reduced to near 0.96when load is added in the system at 0.4Sec. The power factor is improved when capacitor band added at 0.5 Sec and 0.6 Sec to 0.98 and 0.99 respectively.

The power factor on captive generation characteristics with active and reactive power demand as PF is near Zero initially as there is zero active and reactive power demand initially. When the active and reactive power demand increases at 0.4 Sec, power factor improved to 0.95 (in view of less active power demand). When capacitor bank is added in the system at 0.5 Sec, the reactive power demand reduced on the captive power source but the active power demand is same. Hence, active power demand is comparably high then the reactive power demand. Hence, the power factor improved on captive power source.

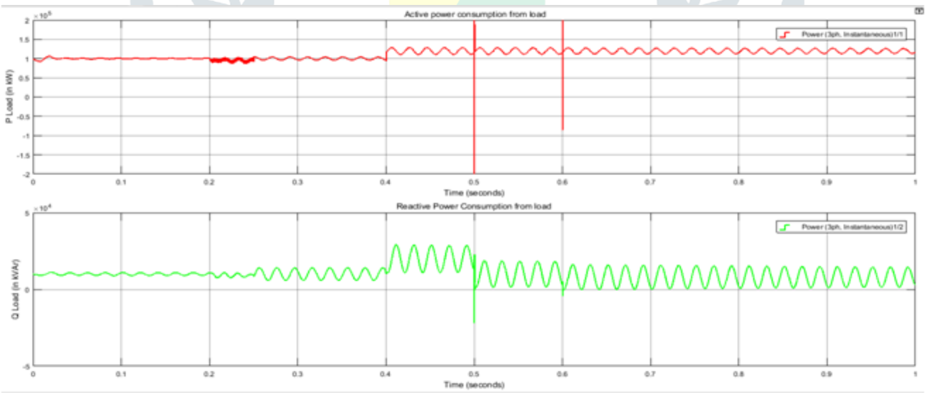


Fig. 13 Load consumption during grid failure with reactive power support

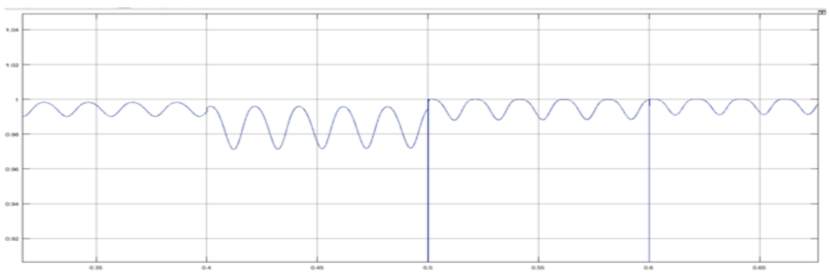

Fig. 14 Load Power Factor Characteristics with reactive power support during grid failure

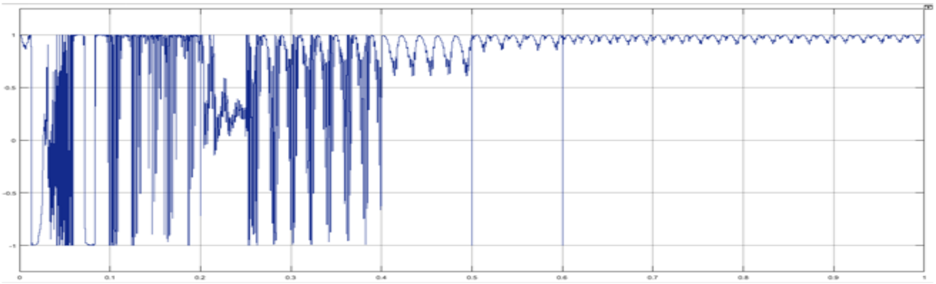

Fig. 15 Captive power source power factor characteristics with reactive power support

Simulation result shows that the active power and reactive power demand on captive system should be balanced, i.e., the power factor of the captive generation plant should not be fall down to the defined power factor range of the generator.

Addition of more and more active power generation in the captive tied system may provide severe impact on the power factor of captive power source, which may intern damage the rotating mechanism of the mechanical system as indicated in the case study.

## VI. Conclusion

In an integrated distribution system where RES and captive power source are connected active power and reactive power demand on captive system should be balanced, i.e., the power factor of the captive generation plant should not fall beyond the defined power factor range of the generator. Addition of more and more active power generation in the captive tied system may provide severe impact on the power factor of captive generation units, which may in turn damage the rotating mechanism of the mechanical system as indicated in the case study of this paper. Hence an appropriate mechanism to balance the reactive power drawn from the captive generation unit is implemented using the services of the locally available reactive power resources.

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