# Peak Time Demand Management Using Distributed Solar Inverters


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***Abstract*—With increasing load demand, the electricity generation in India is also increasing at a significant rate of ~7% per year. India is setting up new power plants, with huge emphasis on renewable power generation. While the increasing generation capacity alleviates the average demand/supply problem to certain extent, one of the main challenges for the utilities is to meet the peak load demand. Utilities find it difficult to develop generation capacities to meet the peak load, since its very expensive, and the peak loads only occur for a short period of time during the seasons. To address this problem, utilities often shed the load during peak times or use advanced techniques like Conservation Voltage Reduction (CVR).The existing utility scale solar inverters have the same hardware architecture and necessary controls to perform other functions like voltage control, reactive power control as required by the CVR, while supplying 100% real power. CVR involves reducing the feeder voltage within the allowable ANSI or IEC limits, thereby enabling reduction in the load. Traditionally, CVR was performed by operating the Load Tap Change (LTC) transformers, or by switching on/off capacitor banks. While this is an effective way of implementing CVR, one of the issues is the wear-tear of the moving components, high response times and only a discrete step change possibility as against a fine control. The paper addresses this topic, and proposes a novel way of voltage control using solar inverters. The geographically distributed solar inverters perform voltage reduction by absorbing reactive power at the PCC, while supplying as much real power as possible. In this paper, simulation analysis will be performed to show the implementation of CVR with distributed solar inverters on a typical 11kV feeder and the obtained energy saving results.**



**Keywords-Solar Inverter, Conservation Voltage Reduction, Voltage Profile, Loss Reduction**


## I. INTRODUCTION

Emission concerns and depleting conventional fuels are increasing the adoption of renewable power generation to meet growing load demand. According to Ministry of New and Renewable Energy, the installed capacity of renewable energy is17.4% [1] of total installed capacity in India. Among the different types of renewable sources, Wind and solar power has become more prominent in the recent years due to decreasing solar panel and balance of system costs. Furthermore, government benefits like rebates, subsidies, feed-in tariffs, etc. have increased interest in commercial grid connected solar systems [1]. India is setting up new power plants, with huge emphasis on renewable power generation. As per the recent projections ~175GW of renewable energy is planned to be installed by 2022, which includes 100GW of solar, 60 GW of Wind, 10 GW of Biomass, and 5 GW of small hydro electric. As per recent Government of India's reports, the average electricity demand-supply gap is decreasing, and is currently at 0.7% [1].

While the increasing generation capacity alleviates the average demand/supply problem to certain extent, one of the main challenges for the utilities is to meet the peak load demand which is typically ~1.5 times the average load. Utilities find it difficult to develop generation capacities to meet the peak load, since it is very expensive and the peak loads only occur for a short period of time. As per the recent reports, the peak demand-supply deficit is ~1% (1.4GW) [1]. While the peak deficit has reduced significantly in the last decade, the emerging trends of electric vehicles, manufacturing emphasis might create a problem for the utilities. Utility scale energy storage solutions are also being explored as an alternative, however they are cost prohibitive at this point of time. Load shedding is an option that the utilities typically use to reduce the peak time demand. The problem with the load shedding is that the utilities have significant revenue loss, which is hence they are used as a last resort.

Apart from load shedding, one of other the traditional ways of addressing the peak load demand is through Conservation Voltage Reduction (CVR). A significant percentage of the loads in a distribution network are constant impedance loads, whose power consumption is directly related to the voltage. A decrease or increase in the voltage reduces or increases the power consumption respectively. CVR is based on this concept, and the voltage is intentionally reduced by the utility (but maintained within the allowed limits of +/- 5%) so that the power consumption in the downstream loads is reduced. CVR as a way of demand side management and its impact on the devices has been studied extensively in the last few decades. This paper introduces a novel way of implementing the CVR using solar inverters and performs simulation analysis to demonstrate it.

## II. SOLAR INVERTERS AS REACTIVE COMPENSATORS

Reactive power is necessary to maintain the system voltage, and lack of sufficient reactive power results in the reduction of system voltage. The traditional way of implementing CVR is through tap changing transformers. By changing the transformer tap ratio, the secondary voltage is reduced, there by resulting in reduced power consumption. While this is a straight forward procedure, it is heavily limited by the granularity of control, inflexibility, slow response speed and reliability concerns of the transformer [2].

The improvements in power electronics enabled IGBT based Flexible Alternating Current Transmission Systems (FACTS) for dynamic reactive power supply or absorption. By absorbing or generating the reactive power flow through the system, the voltage at the point of common coupling can be reduced or increased. The advantage of this approach is the flexibility, granularity, response speed of voltage control operation. However, the FACTS devices are not cost-effective yet.

The converter technology used in the solar inverters and the FACTS devices are the same –voltage source converters. Similar to the FACTS devices, the existing solar inverters use IGBT based switches which can be controlled to generate output at varying power, voltage and phase angles as needed. Figure 1 shows the typical control architecture of solar inverters. As seen the active (P) and reactive (Q) power controls are decoupled. The P control ensures that maximum power is extracted from the solar panels at all times, unless otherwise instructed by the plant level supervisory controller. The Q controls can be used to control the voltage. This concept is utilized in this paper for reducing the voltage.

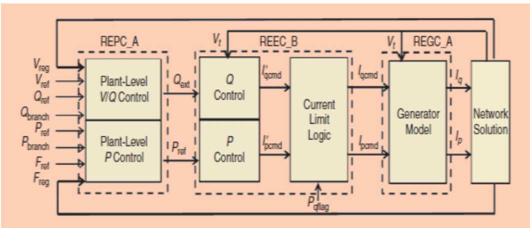


**Figure 1. Typical Control Architecture of Solar Inverter [3]**

Using this feature built into the solar inverters enables the reduction of load during times of peak without having any additional infrastructure requirement. The life time of the existing capacitor banks or tap changing transformers can also be increased [2], due to lesser usage of those. Due to the finer control of Q when compared to "step-wise" change in tap changing transformers, the overall network would be operating in an optimum condition.

The reactive power supplied or absorbed is limited by the current carrying capacity of the switches of the inverter and not by the real power generated. Hence, the reactive power Q can be generated without affecting the real power generation. Recently, there have been a growing number of renewable energy based e-charging stations for the electric vehicles. This concept can be applied to these stations as well; where-in the vehicles connected to the station and the renewables at the station can actively contribute to reducing the voltage at the point of common coupling while also supplying active power from the vehicles back to grid (V2G) at the time of peak demand. The renewable based e-charging stations also have an advantage of being connected closest to the load consumption.

This gives an option where in the grid connected solar plants or the electric-charging stations which use inverter technologies can actively contribute to supply or absorb of reactive power.

Presently, utility scale solar installations in India are used only for active power generation and have Q setpoint disabled or maintained at fixed value. However, with increasing solar penetration, there is a growing need for these inverters to actively support the grid [4]. Keeping in consideration this potential, and the changing grid regulations, many solar inverter manufacturers have started to incorporate this feature in their products. Table 1 shows an example representative comparison of some solar inverters.

**Table 1. Representative Comparison of Some Solar Inverters**

| Manufacturer | Model Number | Var setpoint | Var ramp rate | Full pf range (Lag-Lead) |
|---|---|---|---|---|
| Eaton | Power Xpert 1670 | Y | Y | 0-0 |
| SMA | SC 800CP | Y | Y | 0.8– 0.8 |
| Bonfiglioli | RPS TL-UL 1000 | Y | Y | 0.85– 0.85 |
| Schneider | XC 680-NA | Y | N | 0.8– 0.8 |
| Solectria | SGI 750XTM | Y | Y | 0.8– 0.8 |
| ABB | Ultra 750-1500 | Y | Y | 0.9– 0.9 |

## III. SIMULATION ANALYSIS

Typically, the utility SCADA would receive the voltage, current and power (real and reactive) information of the solar plants connected at the bus. Depending on the network conditions (which the grid keeps analyzing in real time), dynamic setpoints are sent by the utility SCADA to the solar plants to dynamically generate/absorb reactive power without affecting the real power generation. During the peak times when the utility grid wants to impose CVR, a signal is sent to the solar plant or the e-charging stations (instead of changing the tap changes in the transformer) to absorb reactive power to control the voltage.

In order to demonstrate the peak load reduction with dynamic reactive compensation using solar inverters, simulation analysis is performed using power world [5] tool. Figure 2 shows a simple 2 – bus (138kV, 66kV) system with a 100MW solar plant connected at the 66kV bus. It is assumed that the solar is operating at its peak power point. For the sake of simplicity, the load is taken as a constant at 300MW, 10Mvar before the CVR was invoked. Grid is seen as supplying ~200MW load, and solar generates 100 MW.

When the CVR is invoked, the solar plant is requested to reduce the 68kV bus voltage to reduce the power consumption. Accordingly, the solar plant changes to Q control (in addition to MPPT mode), and absorbs Q until what is maximum possible, thereby reducing the voltage at the 66kV bus reduces. It can be clearly seen that the load power consumption has reduced by 5MW without affecting the solar power generation, and the voltage at the bus is 0.98 pu. While there is still a bandwidth available to reduce the voltage (and the load reduction), the available solar capacity is not sufficient to reduce this alone. However, the load reduction brought in is still substantial without any additional cost or reliability constraints. Furthermore, if there are more solar plants available, the load can be further reduced.

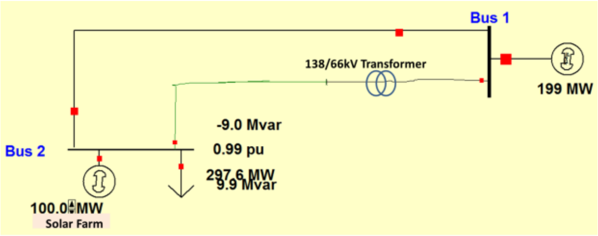


**Figure 2. Simple 2 Bus Power Network (Before CVR)**

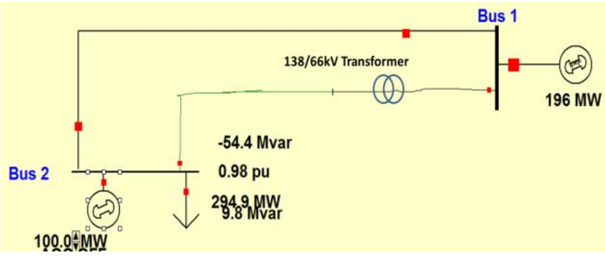


**Figure 3. Simple 2 Bus Power Network (After CVR)**

Figure 4 shows a multi-bus power network from power world [5] tool. The model represents an aggregated rooftop solar plant and electric charging station at bus 4 with a combined 81MW and a large solar farm at bus 7 with power of 180 MW respectively. Tables 2, 3a, 3b shows the performance results of the network under various operating scenarios.

It can be seen that in the base case, before CVR, the voltages in all the buses are perfectly maintained. When the CVR event is invoked at the time of peak demand, the grid SCADA sends a "request for Q absorption" to the solar plants and e-charging station to reduce the voltage at the point of common coupling. In the first case, the units at bus 7 and 4 absorb 25 Mvar respectively, and accordingly the voltages have reduced in the corresponding buses, leading to a reduction in the load demand of 16MW as shown in Table 3a. In the second case, the solar farm at bus 7 is requested to absorb more reactive power until the voltage is to the lower limit. As expected, the power saving has increased and is about 20MW.

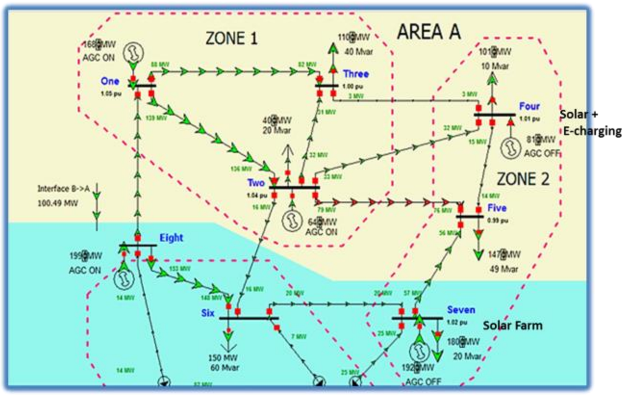


**Figure 4.Multi-Bus Power network**

**Table 2. Parameters – No CVR**

| Bus | Load (MW, MVAR) | Voltage |
|---|---|---|
| 7 | 169, 19 | 1.02 |
| 5 | 138, 46 | 0.99 |
| 4 | 96, 10 | 1.01 |

**Table 2a. Parameters – With CVR**

| Bus | Load (MW, MVAR) | Voltage | Q absorbed by Solar |
|---|---|---|---|
| 7 | 162, 18 | 0.96 | -25 MVAR |
| 5 | 134, 45 | 0.95 | |
| 4 | 91, 9 | 0.96 | -25 MVAR |
| **Power saving obtained = 16 MW** | | | |

**Table 3b. Parameters – With CVR**

| Bus | Load (MW, MVAR) | Voltage | Q absorbed by Solar |
|---|---|---|---|
| 7 | 159, 18 | 0.95 | -28.3 MVAR |
| 5 | 134, 45 | 0.95 | |
| 4 | 89, 9 | 0.95 | -25 MVAR |
| **Power saving obtained = 20 MW** | | | |

## IV. CONCLUSION

Solar inverters have the capability to dynamically absorb reactive power depending on the network conditions without requirement for any additional infrastructure costs. Simulation analysis has shown that this feature of the inverter can be exploited as a viable alternative for CVR when compared to traditional transformer tap-change method. Simulation analysis was performed to show the benefits using this method.

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