Coordinated, Real-Time Grid Balancing Using Distributed Solar Inverters

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***Abstract*—The intermittency of the renewables coupled with increasing load demand is going to pose several grid balance challenges like: voltage stability, active and reactive power excursions etc., Such a high renewable penetration is also anticipated to cause significant grid congestion since the existing transmission and distribution lines have limited transfer capacities. One of the ways of addressing this issue is by installing passive capacitor banks or inductive filters, or more recently by adding separate active compensation devices like STATCOM, SVC etc. This however would pose lot of challenges as the renewable penetration increases and would require more of these devices to be added to the grid, which involve high infrastructure costs. The paper addresses this topic, and proposes a novel methodology for grid support where-in the existing solar inverters connected to the substation are dynamically and intelligently controlled to ensure that the voltage profile is maintained. Simulation analysis will be performed to show the effectiveness of the proposed coordinated grid support functionality through geographically distributed solar inverters connected to same and different substations. While the proposed concept is being studied at a MW scale inverters level, the same philosophy would apply for smaller rooftop inverters as well with the added advantage that high incidence of losses in the LT network can be efficiently controlled.**

Keywords-Solar Inverter, Reactive Compensation, Voltage Profile, Losses

I. INTRODUCTION

Emission concerns and depleting conventional fuels are increasing the adoption of renewable power generation to meet growing load demand. Of the different forms, solar power has become more prominent in the recent years due to decreasing panel and balance of system costs, easier implementation and the capability to be installed at different points in the distribution network. Furthermore, government benefits like rebates, subsidies for the initial cost of the system, feed-in tariffs, etc. have increased interest in commercial grid connected solar systems [1].

Technical losses in Indian power Transmission and Distribution (T&D) is still very high In India. Average T & D losses, have been officially indicated as 23 percent of the electricity generated. However, as per some studies losses have been estimated to be as high as 50 percent in some states [2]. Some of the reasons for this include: improper load management, inadequate reactive power compensation, poor power quality.

Proper reactive power compensation in the electrical network improves the stability of the ac system by maintaining a substantially flat voltage profile at all levels of power transmission, thereby leading to reduction in feeder and equipment losses. It also helps in increasing the maximum active power that can be transmitted. Traditionally, rotating synchronous condensers and switched capacitors or inductors have been used for reactive power compensation. During the last decade static Var compensators (SVCs) employing thyristor-switched capacitors (TSCs) and thyristor-controlled reactors (TCRs) are being used to provide or absorb the required reactive power have been developed. More recently, with the improvements in the power electronics, IGBT based Flexible Alternating Current Transmission Systems (FACTS) are being used for reactive compensation [3]. The advantages of FACTS devices are the flexibility, speed and range of operation. However, they are not cost-effective yet.

Presently, utility scale solar installations in India are used only for active power generation. However, with increasing solar penetration, there is a growing need for these inverters to actively support the grid. The paper addresses this topic, and proposes a novel methodology for grid support where-in the existing solar inverters.

II. SOLAR INVERTERS AS RECTIVE COMPENSATORS

At the core, the converter technology used in the solar inverters and the FACTS devices are the same –voltage source converters. The existing solar inverters use IGBT bases switches which can be controlled to generate output at varying power and phase angles as needed [4]. 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 control maintains the voltage at the point of common coupling by absorbing or supplying reactive power.

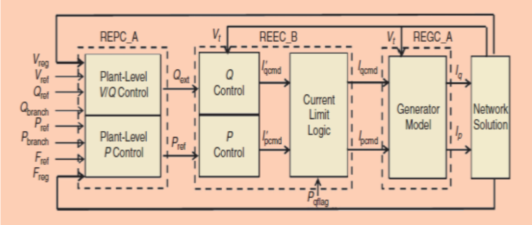

Figure 1. Typical Control Architecture of Solar Inverter [5]

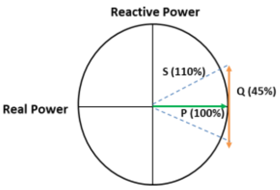

Figure 2. Power Triangle

Figure 2 shows the typical power triangle. It can be observed that with a little over-rating of the solar inverter to 110%, the inverter can generate 100% real power and also generate/absorb upto 45% reactive power. Since the maximum real power from the solar plants happens for a short duration of the day, it can be clearly seen that even with nominal (100%) rated inverters, significant reactive power can be generated.

The reactive power 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 also be generated at night even when the real power is not generated. Most of the utility scale solar plants have some sort of auxiliary power (typically battery or Diesel generator) for keeping the transformer or electronic equipment or miscellaneous loads like lights, HVACs etc energized at night. Losses during the reactive compensation at night can be powered by this auxiliary power supply.

Using this feature built into the solar inverters enables the reduction of line losses without having any additional infrastructure requirement. Furthermore, the life time of the existing capacitor banks or tap changing transformers can be increased [1], due to lesser usage of those. Due to the finer control of Q when compared to “step-wise” change as in capacitor bank, the overall network would be operating in an optimum condition. However, presently the Q controls in most of the solar plants are either disabled or maintained at fixed “Q” setpoint. The Q is not varied in accordance with the grid conditions.

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. With the changing regulations worldwide, it is clear that in future, more number of features like these would be added into the inverter functionalities [4].

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. ARCHITECTURE AND SIMULATION ANALYSIS

Figure 3 shows basic high level architecture of the proposed concept of dynamic reactive power compensation using solar inverters.

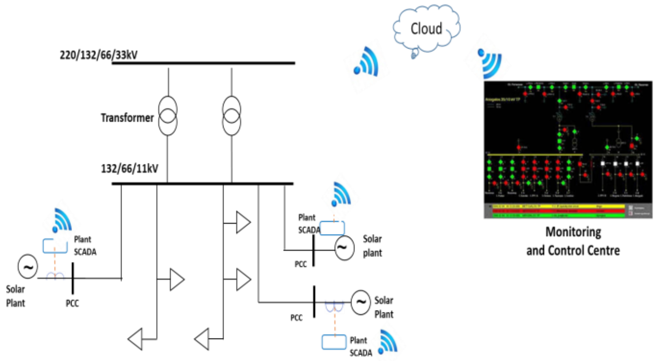

Figure 3. Basic Architecture

Apart from the network level voltage, current and power (real and reactive) information, the substation SCADA typically receives this data of the utility scale solar plants connected at the bus. Depending on the network conditions (which the grid keeps analyzing in real time), dynamic setpoints are sent to the SCADA of the solar plants to dynamically generate/absorb reactive power without affecting the real power generation. As the solar power penetration increases in the grid, it becomes necessary to coordinate the reactive power contribution of each of these plants.

While developing a full-fledged optimization algorithm is out of the scope of this paper, the algorithm should be essentially doing the following steps:

1. Analyze the network power flow every 15 mins and determine the buses where the voltage profile is weak or ones which have high reactive loads and reactive compensation is needed
2. Determine the closest possible solar plants that can generate the reactive power.
3. Run continuation power flow and determine the extent of reactive compensation (Q setpoint) is needed at that possible, and how much can be supplied by that plant.
4. Analyze the impact of the reactive compensation on the other buses, and change Q setpoints at other plants accordingly.

In order to demonstrate the performance improvement with dynamic reactive power supply through solar inverters, simulation analysis is performed using power world [6] tool. Figure 4 shows a simple 2 – bus (33kV, 11kV) system with a 5MW solar plant connected at the 11kV 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 25MW, 5Mvar.

Table 2 shows the power flow simulation results under different operating scenarios. It can be seen that with the solar supplying Mvars, the voltage profile in both the buses have improved when compared to the base case. This is because, the local supply of reactive power has more impact on the voltage profile.

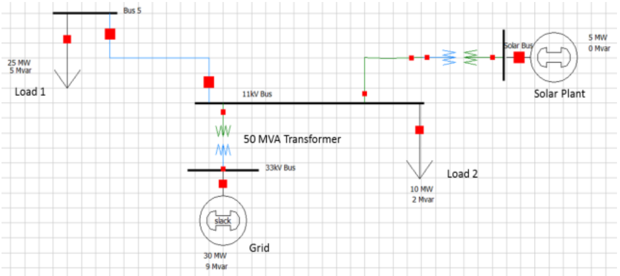

Figure 4. Simple 2 Bus Power Network

Table 2. Power Flow Results

Bus	**Without reactive support**	**With 2.5MVAR support**	**With 5 MVAR support**
33kV	1	1	1
11kV	0.984	0.989	0.992
Load 1	0.982	0.986	0.992
VARs supplied by Grid	9	7	4

Figure 4 shows a multi-bus power network from power world [6] tool. The model represents two solar farms connected at bus 4 and 7 respectively and with an aggregated power of 81 MW, and 180 MW respectively. Table 3 shows the performance results of the network under various operating scenarios.

It can be seen that in the base case, the voltage at bus 3 is less than the allowed limit of +/- 5%, and in other buses it is close to limits. In the first case, with the solar at bus 7 and 4 supplying 60 Mvar and 30 Mvar respectively, the voltages have improved in all the buses, but there is an over voltage in the bus 2. To reduce this over voltage, the capacitor bank at bus 2 is invoked to absorb some reactive power, resulting in bringing back the voltage. However, now the bus 5 is closer to the limits. The last scenario represents a case where after several rounds of optimization, the final values of reactive power supply from different buses are given. It can be seen that the voltage across all the buses are now high and close to optimum.

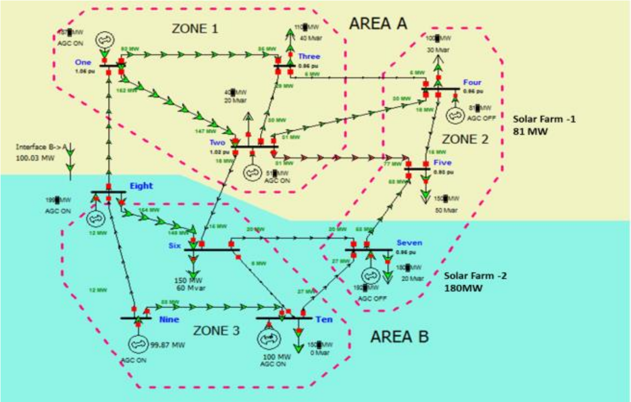

Figure 5. Multi-Bus Power Network

Table 3. Power Flow Results - Multi Bus

Bus	**Bus Voltage (in pu)**			
	Without reactive support	**With 60 MVAR at Bus 7 and 30MVAR at Bus 4**	**With 60, 30, -40 MVARs at Bus 7,4,2 respectively**	**With 67, 30, -40 MVARs at Bus 7,4,2 respectively**
7	0.95	1	0.99	1
5	0.93	0.98	0.96	0.97
4	0.95	0.99	0.97	0.99
2	1.02	1.05	1.01	1.02

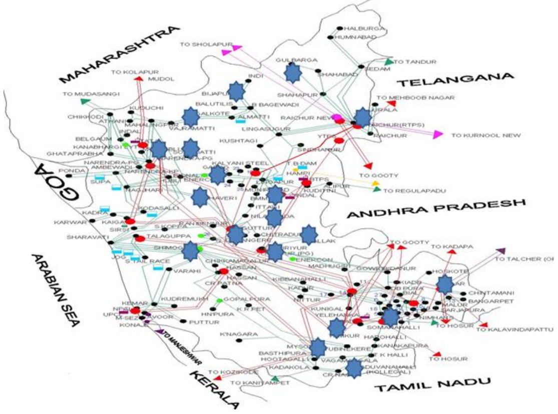

Figure 6. Representational Picture Showing MW Scale Solar Plants in Karnataka

Figure 6 shows a representational picture of the areas within Karnataka, India that has utility scale solar plants as of 2016. It is to be noted that it is not a complete or exhaustive list of all the solar plants. From the earlier discussion, it can be clearly seen that by dynamically controlling the reactive power setpoints of the solar plants spread geographically within the network, the overall power grid can be maintained at efficient voltage levels, thereby reducing significant losses and maintaining voltage stability.

Presently, in India there is no clear regulation for reactive compensation with renewables, though at the time of this paper, it was learnt that a draft regulation is being developed. Features like this can be immensely beneficial to improving the health of the network without adding any extra burden of costs on the financially stressed distribution grid.

IV. CONCLUSION

Solar inverters have the capability to dynamically absorb/generate reactive power depending on the network conditions without requirement for any additional infrastructure costs. Simulation analysis has shown a significant improvement in the voltage profile (hence the losses reduction) by dynamically controlling them.

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