# Economic Source Allocation among Multiple Distributed Energy Resources in Regulatory Markets

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**ABSTRACT—** ***Secure, reliable and economical solution for intermittent power problems is possible through active participation of converters powered by various distributed sources. This paper concerns with the allocation of resources based on pricing policy in regulatory markets. DERs at the bay level can participate in energy trading and ancillary services. Pricing signal from various resources is send to the station level central controller. The cheapest resource is then given the initiation signal to participate in power trading. The field controller gives multifunctional features to the converter at the bay level such that it exhibits bidirectional power transfer capability, load balancing and harmonics mitigation features. A utility management system where evaluations are done with priority on cost benefits allows customers to avail less expensive resources and also they get incentives for the ancillary services provided by their cheaper resources. Centralized operation of resources in a smart micro grid under varying energy prices is demonstrated. A MATLAB/ SIMULINK model has been developed with an inductive and nonlinear load to show the effectiveness of the proposed project.***

**Keywords—** Distributed Energy Resources, Centralized Operation, Pricing Controller, Ancillary Services.

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## 1. INTRODUCTION

Decentralized generation using dispatchable and non dispatchable sources like solar, wind and fuel cell are gaining popularity because of soaring energy prices. The concept of energy trading provides merits both at utility level and consumer level. At the utility level power quality is enhanced whereas at the consumer level the customer gets a better chance to avail cheaper resources. Several energy producers at the bay level can enter into an agreement as to provide real power support and other ancillary services like reactive power compensation, current harmonics mitigation and load balancing. Thus the loads connected at PCC get an opportunity to get better quality of power. At the same time abnormalities in the grid power are solved by using DER inverters. The converter is operated in a plug and play model so that it can act either in centralized mode or distributed mode [1].

Decentralized generation is possible only with the use of power electronic interfaces between the resource and the grid [2]. Low voltage profile of these units can be stepped up using boost converters. The voltage has to be at least 1.6 times the grid voltage enabling proper integration. Cascaded connection of boost converters is an inefficient solution because the efficiency reduces with increase of stages. For solar photovoltaic sources, a high gain boost converter can be used as it provides maximum power tracking for similar insolation levels as compared to other converters. Ordinary converters have to be operated at a very high duty ratio causing reverse recovery problems and electromagnetic interference [3]. Such issues can also be avoided by employing High gain boost converters. In this paper a voltage source converter is used. Usage of appropriate control algorithms provides enhanced features to the converter such as it can be operated as a bidirectional converter feeding ac and dc loads.

A suitable MPPT controller maintains dc link voltage constant. Instantaneous symmetrical components theory is used to produce reference currents. Fast response is the main advantage of using this control theory. Actual currents accurately track reference currents and produce the desired gate signal pattern to each switch of the converter. Bidirectional power transfer capability with enhanced power quality operation of the converter chosen based on pricing are the important issues faced in this paper. The paper is organized as follows. Utilities must develop a suitable methodology to integrate DER and other small renewable in the most cost effective manner [4]. It is assumed the entire DER connected at the customer level has some type of power electronic interface and are owned by either residential, customer or industrial loads.

DER sources could be of several types including solar photovoltaic panels, fuel cell and wind. Each resource has different pattern of fuel cost. Depending upon environmental and other geographical reasons some resources will be available plenty at a cheaper rate. During such situations the customer gets a chance to avail cheaper resources through economic allocation of available resources. In this paper , two solar photovoltaic panels of different rating whose output power varies with the irradiation levels is chosen as the der sources. Day by day the owner of solar panels sends a pricing pattern for different intervals of time during a daytime to a central price controller which selects the cheapest resource from the available ones. The cheaper resources satisfies load demands as well as provide ancillary services like reactive power compensation, current harmonics mitigation and load balancing The paper is organized as follows; first part deals with the system description, modeling and control, second part is about field controller used to impart multifunctional features to the converter and the supervisory pricing controller used to select the cheapest resource from the available resources. Finally a MATLAB Simulink model is developed to verify the effectiveness of the proposed project.

## 2. SYSTEM MODEL AND DESIGN

### 2.1 System Description

System consists of two resources connected to the grid via a voltage source converter. An external supervisory price controller receives the pricing signal from the two sources. It gives the initiation signal to the cheapest converter. The selected converter with the help of field controller meets the demands of the ac load connected at PCC and DC loads at the dc link. The system is as shown in Figure 1.

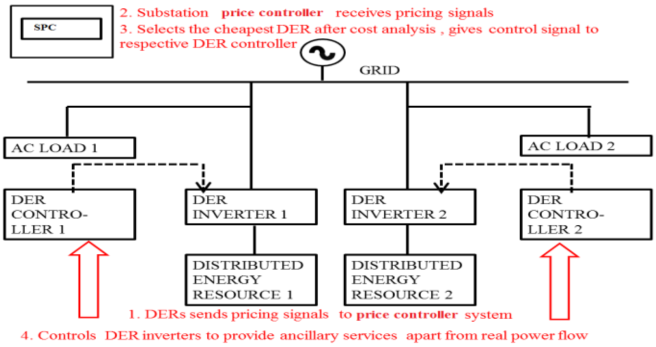


**Figure 1:** Overall system under consideration

The distributed energy resources may be a solar photovoltaic panel or a wind turbine present at the consumer level. These resources are capable of operating in a stand-alone mode and grid connected mode. In the standalone mode they are capable of meeting dc loads as well as ac loads connected at the converter side. In the grid connected mode these resources can participate in regulatory markets so that the consumer gets a better choice of utilizing cheapest source of energy. Two or more of DERs can bid their prices to the central station following the substation communication protocol. The central station receives the time varying pricing signal from various kinds of resources. The supervisory pricing controller at the central level compares the prices and selects the cheapest resource available for that particular instant of time. The cheapest resource selected gets an initiation signal, which then meets the load demands. If the total load demand is greater than the cheapest resource capacity, then the second resource is selected to meet the excess load demand. If excess loads still persist, it is met by grid. The selected resource has an additional feature of reactive power compensation, current harmonics reduction and load balancing. Thus the consumer gets additional incentives for providing the above mentioned additional features.

### 2.2 Supervisory Price Controller

The main aim of the controller is to select the cheapest resource from the available ones based on cost benefit analysis. The prices bid by the two resources as shown in table below.

**Table 1:** Pricing Scheme of resources

| ***Source*** | ***Time Interval*** | | |
|---|---|---|---|
| | ***0-0.1*** | ***0.1-0.2*** | ***0.2-0.5*** |
| DER1 | 8 | 6 | 8 |
| DER2 | 10 | 4 | 10 |
| GRID | 15 | 15 | 7 |

The participating micro resources are effectively coordinated with changing price policy using this controller. The prices of renewable resources connected to the grid are fetched. The two prices along with the grid electricity price are compared and the cheapest resource is given the initiation signal. In the first interval DER 1 is cheaper than others which then meets the load demands. If the selected resource has a higher capacity, then excess power is absorbed by the utility grid. On the other hand if the load cannot be met by DER alone, the remaining is met by grid.

### 2.3 DER controller

Instantaneous symmetrical component theory is utilized in this controller for the generation of reference current waveforms. In this paper two individual field controllers provides enhanced multifunctional features to the two converters associated with each resource. The converter operating with this controller works as a bidirectional converter as well as a power quality compensator. Moreover this controller helps in load balancing, harmonic suppression, and power factor correction. Fundamental values of positive sequence voltages and currents are used for generation of reference inverter current waveforms.

$$i^*_{inv,a} = i_{l,a} - \frac{v_{s,a}P_{lavg}}{\sum_{j=a,b,c} v_{sj}^2} - \frac{(v_{s,b} - v_{s,c})\beta(P_{lavg} - P_{panel})}{\sum_{j=a,b,c} v_{sj}^2} \quad (1)$$

$$i^*_{inv,b} = i_{l,b} - \frac{v_{s,b}P_{lavg}}{\sum_{j=a,b,c} v_{sj}^2} - \frac{(v_{s,c} - v_{s,a})\beta(P_{lavg} - P_{panel})}{\sum_{j=a,b,c} v_{sj}^2} \quad (2)$$

$$i^*_{inv,c} = i_{l,c} - \frac{v_{s,c}P_{lavg}}{\sum_{j=a,b,c} v_{sj}^2} - \frac{(v_{s,a} - v_{s,b})\beta(P_{lavg} - P_{panel})}{\sum_{j=a,b,c} v_{sj}^2} \quad (3)$$

Where β is the power factor coefficient, Vs represents source voltages, $P_{lavg}$ is the average power consumed by the load over a half cycle and $P_{panel}$ is the dc power provided by the panel for a particular irradiation. Under perfectly balanced condition, instantaneous power is equal to active power. During unbalance conditions, instantaneous power oscillates at twice power system frequency due to presence of zero sequence components. In this paper average power consumed by the load is found using instantaneous reactive power algorithm. Thus the theory of instantaneous symmetrical components can be used for the purpose of load balancing, harmonic suppression, and power factor correction.

## 3. DESIGN AND SIMULATION

The utility is represented by a voltage source and linear or nonlinear loads represent other customer loads. The pricing controller consists of incoming price signals and the output of this controller serves as the initiation signals to the individual DERs. The DER controller subsystem mainly consists of positive sequence analyzer and a unit sine wave generator. Two three phase IGBT full bridge converter with antiparallel diodes provides sinusoidal waveform of sufficient amplitude to be integrated to the grid. The coupling inductor offers high impedance to the high frequency current ripples and low impedance to the harmonic components. Simulation is done using a three phase source acting as the grid with a phase voltage of 415V and 800V voltage at the dc side. The overall circuit diagram is given in Figure 2. Simulation is done with a three phase inductive load of 5kW and 3.75kVAr and nonlinear load of 5kW.

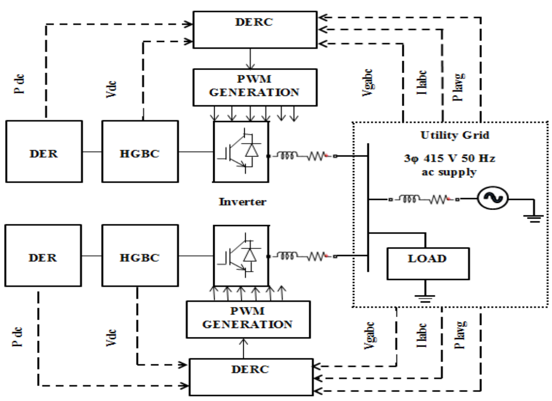


**Figure 2:** Overall Circuit diagram

**Table 2:** DER Parameters

| *Resource* | *Capacity* |
|---|---|
| DER1 | 25 kW |
| DER2 | 12.5 kW |

**Non Linear Load:**

A three phase Diode bridge rectifier load of 5 kW with a resistance value of 45 ohm kept at the dc side serves as the customer load.

**Inductive Load :**

A three phase 5 kW, 3.75 kVar inductive load such that there is is 0.8 power factor lag between voltage and current acts as the second type of load at the customer side.

**Table 3:** Design Parameters

| *Parameter* | *Inductive Load* | *Non Linear Load* |
|---|---|---|
| Voltage (per phase) | 415 V | 415 V |
| P load | 5 kW | 5 kW |
| Q load | 3.75 kVAr | 0 |
| Coupling Inductor (Lf) | 3.5 mH | 3.5 mH |

## 4. RESULTS AND DISCUSSION

The simulation is run for a total time of 0.5 seconds and this interval is divided into three main instants. In the first interval 0-0.1 seconds, DER1 is cheaper as compared to other available resources. Further it is assumed that the grid is always connected to the load so that if a case arises such that the resources are unable to meet the entire load demands, the remaining is met by the grid. Also an interconnection between the load and grid is inevitent to be present as the excess currents are to be absorbed by the grid if the load capacity is less when compared to DER capacity.
Simulations are done for inductive load and nonlinear load. In all these conditions source currents are made sinusoidal and at unity power by the compensating action of the voltage source converter with the aid of appropriate controller. Power management between the grid and the available resources are also well understood form the simulation results given in figures below.

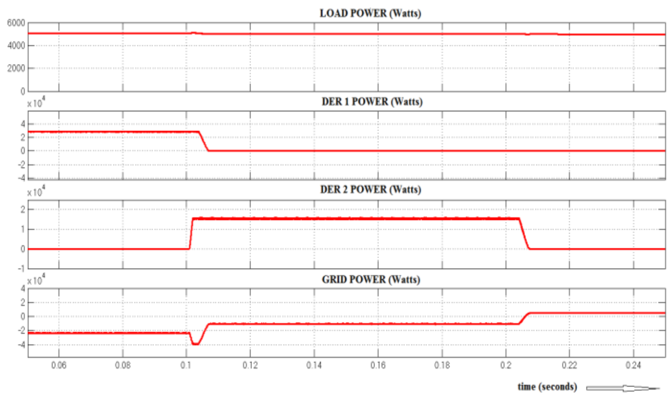


**Figure 3**: Active Power flow for a linear inductive load.

Simulation is done for both linear and nonlinear loads. Figure 3. shows efficient coordinative action between the resources of 25 kW and 12.5 kW panel capacities and the grid to meet the total inductive load demand of 5kW, 3.75 kVAr where the currents in each phase lags behind voltage by 30 degrees. In the interval 0-0.2 seconds, grid power is negative which clearly indicates that the balance power after meeting the load is given to the grid. If the load is further increased to such an extent that it could not be met by DER1 alone, then the next cheaper resource is given the initiation signal for active power transfer. At the start of second interval, the power injected to the grid is found to be slightly greater, because both DERs are found to be ON dut to the delaying of switch to be ON or OFF.

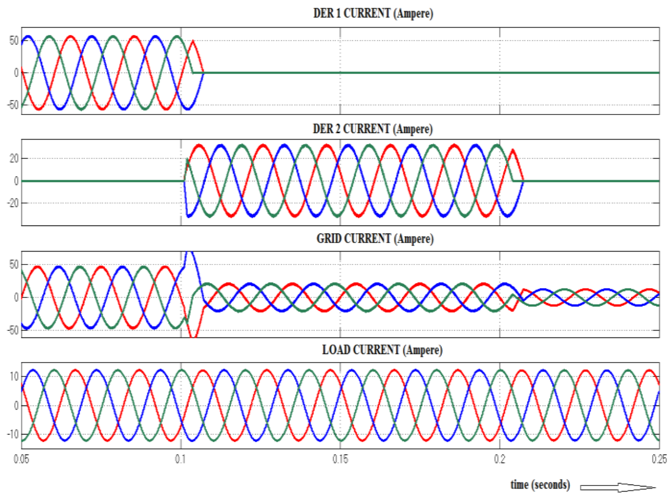


**Figure 4:** Current waveforms of DERs, grid and load during coordinative action for an inductive load

When an inductive load is present at the point of common coupling, it requires a current of 12A. DER1 being the cheaper resource in the first interval is capable of providing a total of 56 A. Therefore, the grid absorbs the remaining 45 A of current. In the second interval of 0.1-0.2 seconds, DER2 provides 32 A of current of which 20 A is taken by the grid. During the last interval grid is cheaper, a low initiation signal is given to both resources. Grid alone meets the entire load demand which is clearly seen in Figure 4.
Grid voltages and currents are not in phase during the last interval due to the absence of compensating action of inverters. Both DERs are in the OFF state during 0.2-0.5 seconds. The energy from these resources could be stored using a battery so that it can be used again during off peak hours when irradiation is too low in case solar photovoltaic modules are used as the distributed energy resources.

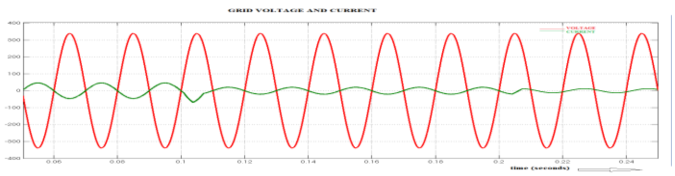

**Figure 5:** Utility voltages and currents in presence of inductive load verifying upf operation

From 0-0.2 seconds, presence of both DERs helps in maintaining unity power factor operation. Current is absorbed by the grid and hence current is 180 degree out of phase with utility voltage But in the last interval a lag between voltage and current is seen due to the absence of reactive power compensation by the DERs as in Figure 5. The current waveforms become sinusoidal even though the load currents are distorted for a nonlinear load.
DER1 has 25 kW capacity, therefore the entire load demand of 5 kW is met by DER 1 alone and the remaining 20 kW is given to the grid. The current waveforms are given in figure 1.1. It is seen that the load requires a current of 8.8 A. DER 1 provides a total current of 56 A of which 8.8 A is taken by the load and the remaining 47.2 is absorbed by the grid. Also the grid voltages and currents are found to be in phase. Thus DER1 is capable of providing real and reactive power support thereby making utility currents sinusoidal and at unity power factor. In the second interval DER 2 is found to be cheaper than the first resource as computed by the supervisory price controller. Therefore a low signal is given to the first breaker of DER 1 and a high signal to the breaker associated with the second resource. DER2 is of smaller capacity of 12.5 kW. Thus only 7.5 kW is provided to the grid. From the current waveforms it is evident that DER 2 is able to provide a total current of 30 A and the remaining 21.2 A of current is absorbed by the grid. The utility currents are still sinusoidal and at unity power factor because of the compensation effect of the voltage source converter. During 0.2-0.3 seconds neither of the resources is cheaper. Therefore the command signals are given to neither of the resources. The grid supports the load and as the compensating effects are absent the utility currents are no longer sinusoidal. The above discussed results are for a nonlinear load of 5kW.

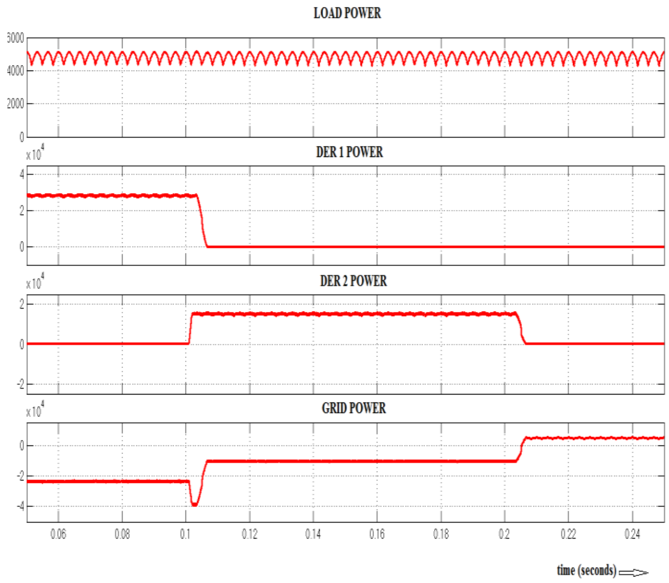


**Figure 6:** Active power flow in case of a nonlinear load

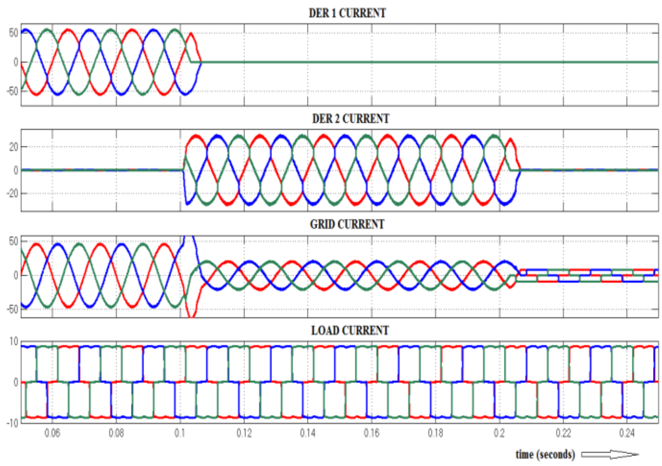


**Figure 7:** Current waveforms of DERs, grid and load during coordinative action for a nonlinear load.

Results of FFT analysis on source and load currents for a non linear load are shown in Figure 8 and Figure 9.THD is reduced from 29.27% to 3.3%.

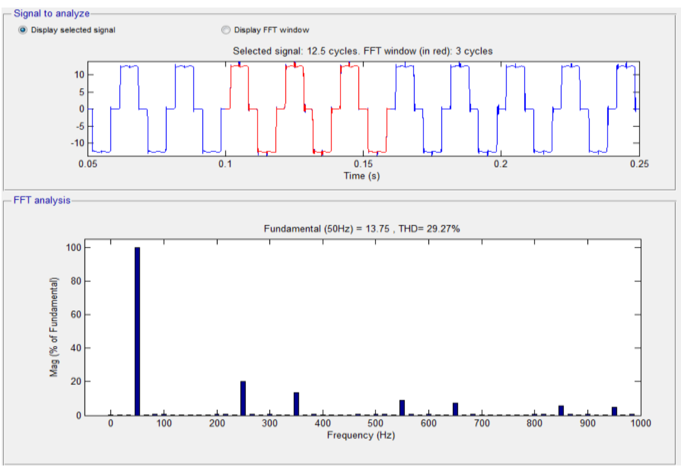


**Figure 8:** THD of load current

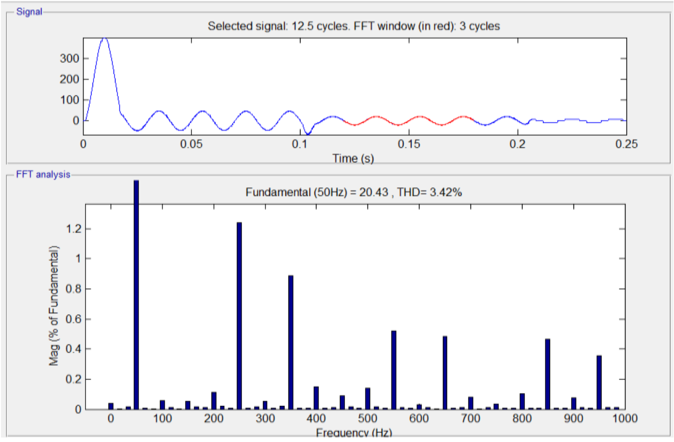


**Figure 9**: THD of source current

## 5. CONCLUSION

Simulation is done for inductive and nonlinear load. Results clearly verify the proposed method can be utilized for any type of loads. Depending on the pricing the customer gets a chance to avail cheaper resources. Significant contribution to power balance on utility distribution system is demonstrated in this project. Control of multiple resources centrally increases effectiveness of energy consumption and guarantee reliability and quality of supply. Only current compensation is illustrated. Control for voltage compensation in case of sag and swell can be included such that overall effectiveness is improved. Furthermore increased functionality and efficiency of electric energy conversion and transfer is seen. Thus a plug and play model of converters under varying energy prices is explained in this paper so that the converters can act either in centralized or distributed mode.

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