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Optimization of Micro grid with Demand Side Management

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In a smart grid environment, economic operation means not only to economically schedule the generation, but also to schedule the load. In a Microgrid (MG), which comprises of intermittent DGs (eg. solar and wind energy sources), the need of Demand Side Management (DSM)/ Demand Response (DR) becomes significant. The key point in DSM is to shift the load to some other point of time, on the other hand shifting the load causes inconvenience to the customer, and hence it has to be minimized. This will become a multi-objective optimization problem to minimize the cost of generation and inconvenience caused due to the shifting of loads. In this work the authors consider an industrial/ commercial MG with one solar source, two diesel generators and one battery, with the assumption that the utility grid uses dynamic pricing. The objective function contains discontinuous function which will be difficult to solve using conventional optimization techniques and hence Genetic Algorithm based solution is proposed. The simulation results show that there is a savings with DSM compared to without DSM.

Keywords: *Microgrid, Distributed Generation, Optimization, Demand Side Management*

1.0 INTRODUCTION

According to Central Electricity Authority, India, 52% of installed capacities in India are thermal power plants and only 9% is Renewable Energy (RE) [1]. Due to environmental factors and considering the depletion of fossil fuel reserves in the near future, we should consider renewable energy resources more seriously. But, large scale integration of renewable energy sources to the power grid posses some serious problems. Power Grid Corporation of India Limited (PGCIL) has released a technical report [2] which discusses the challenges in large scale renewable energy integration. According to the report, the major challenges are,

- Since the renewable sources are intermittent in nature it requires more reserve / spinning capacities for the smooth operation of the grid.
- In a case when large amount of renewable sources and very few synchronous machines are running, the total grid inertia will be reduced. Thus it makes difficult for system operator to maintain the system frequency in permissible limit.
- Power electronic converters used for renewable energy integration will inject harmonics to the grid.

Also the report discuss the possible solutions for the above challenges, they are,

- Flexible Generation and Generation Reserves for fast ramp up and ramp down in response to the supply variations from wind energy and solar energy sources.
- Demand Side Management (DSM) or Demand Response (DR) through Smart Grid is good option to increase the flexibility

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of the grid in order to accommodate the intermittent RE sources.

- Energy Storage Devices can handle excess RE generation during off demand period and can supply back the stored energy during peak demand period.

Microgrids can also be used for RE integration and to increase the reliability.

2.0 MICROGRIDREVIEW

2.1 Distributed Generation (DG)

Distributed Generation is referred to the application of small generators (Distributed Generators/Micro-sources), with typical capacity range 15kW-10MW, distributed throughout the power system in order to provide electric power to the end customers [3]. They may be located at the utility side itself or at customer side or isolated (not connected to the grid). DGs are efficient way to reduce environmental pollution, transmission losses and grid congestion. Following are the generation technologies used in DG [3, 4].

Micro-turbines: in 25-100kW range. These are high-speed turbines mounted on a single shaft and with simple mechanical structure and uses clean fuel (natural gas, propane etc which has low particulates). It can be used in Combined Heat and Power (CHP) system, which recovers the heat released to the sink and uses for community or individual heating purposes.

Fuel Cells: Here electric energy is generated by combining Hydrogen and Oxygen to form water. They offer very high efficiency and zero emissions (as the by-product is pure water). 200kW range phosphoric acid fuel cells are commercially available. They face the disadvantage that, it is very expensive and produce low-voltage and high-current DC power which needs a DC to AC converter.

Renewable Energy: Solar energy and wind energy are the most widely used renewable energy resources. Solar energy is converted into DC power using photo-voltaic (PV) cells and interconnected to AC system using power electronic converter which is capable of extracting maximum power. Wind energy is utilized by using induction generators, DC generators with DC to AC converters and Variable-speed AC drive. Wind energy and solar energy are highly intermittent and non-dispatchable. Bio-gas fueled micro-turbines, fuel cells etc. are also considered as renewables.

2.2 Microgrid Architecture

If the DGs (both intermittent and consistent) of a locality or a distribution network are interconnected together along with necessary storage systems and a control center, can form an autonomous grid termed as a “Microgrid (MG)”, which can solve some of the issues associated with Distributed Generators (DG) in grid integration [5]. It can serve both in Grid Connected mode and in Islanded mode. In grid connected mode, the excess power generated by the MG will be fed to the utility grid and the excess power consumed is drawn from utility grid. Due to various reasons the interconnection with the utility grid may be lost, during this situation the microgrid switch to islanded mode and continue supplying power to customers by generating the required power from the DGs alone. Thus the continuity of supply is ensured.

Consortium for Electrical Reliability Technology Solutions (CERTS) has given clear explanations of the Microgrid concept in a white paper published by them [4]. It gives a brief account of key issues in a MG such as control, protection, economics etc. Figure 1 shows the architecture of the CERTS microgrid. The point at which the microgrid is connected to grid is termed as Point of Common Coupling (PCC). Here the loads are divided into two categories viz., sensitive loads (L1, L2 and L3) and traditional loads (L4, L5 and L6). Sensitive loads are those which need high quality power supply without interruption like semiconductor manufacturing, textile mills, paper mills, plastic injection molding etc [6] and traditional loads are those which do not require high quality power, e.g. like lighting and heating loads. When a disturbance occurs in the utility grid the sensitive loads are separated from the utility grid by a Separation Device (SD) which can be a circuit breaker and power is supplied by the DGs (provided DGs have enough generation) while the non-sensitive loads are still connected to the grid and run with the disturbance.

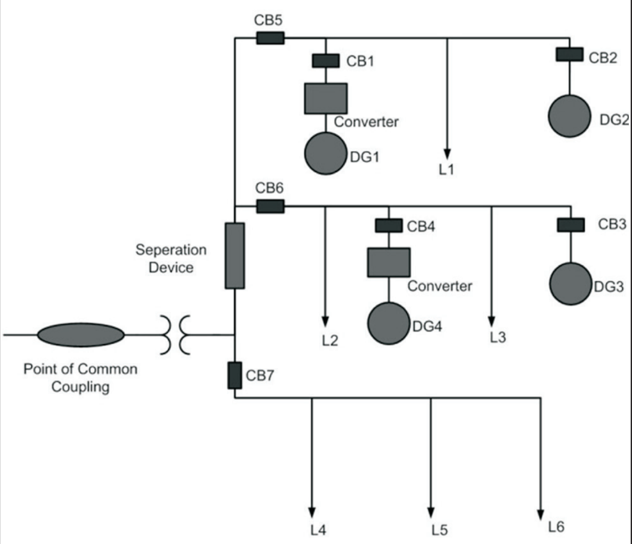

FIG. 1 CERTS MICROGRID

Reference [7] proposes a Power Electronic Transformer (PET) at the PCC, which will allow only restricted power to flow between the MG and main grid. This will allow seamless transfer between islanded mode and grid connected mode. Also PET makes an asynchronous connection between the MG and utility grid, hence synchronization not needed while connecting back to utility grid from islanded mode.

Energy sources in MG are mostly interfaced using DC-AC converters (for PV panels, fuels cells etc.), induction generators (wind energy) and small synchronous generators (diesel engine, bio-gas etc.). Since the number and size of synchronous machines connected to the MG are low, the total inertia of the MG will become less. So there will be huge variations in frequency even with small change in load. Thus fast-responding energy storage systems are necessary to balance the generation and load [8]. And also, DGs are mostly being intermittent in nature so the role of storage systems in microgrid is significant. Reference [9] discusses the various types of storage systems used for DERs such as flywheel systems, super-capacitors, battery systems (NaS & Li), Compressed Air Energy Storage (CAES) etc which can be used in a microgrid system.

2.3 Control of Microgrid

During grid connected mode voltage and frequency of the MG is determined by the utility grid (if PET is not used at PCC), so in grid connected mode the control operations are done mainly for economic operation of the MG. But, when MG is islanded there should be a control system for the MG to keep its frequency and voltage inside the limits and also to match the demand and generation of active power and reactive power [8], thus in islanded mode control objective changes to regulate frequency and voltage [10].

During grid connected mode the voltage and frequency is determined by the utility grid, so there is no need of much control operation during this mode. This is the reason why most of the study is carried out in islanded mode since it is more challenging. But in a smart grid environment, with many technologies like self healing, automation etc. [14,15], the probability of failure in the main grid is quite low. So most of the time the MG will be running in grid connected mode, thus the optimal operation of MG during this mode becomes critical. So the major control objective in grid connected mode should be optimal operation [10-11].

3.0 DSM AND MG OPTIMIZATION

Control at the load side is termed as DSM [12, 13, 16-19]. DSM alters consumer's energy consumption so as to make necessary changes in the supply load profile [19]. From DSM perspective, loads are classified as controllable, semi-controllable and uncontrollable. Controllable loads are those loads whose usage can be shifted to some other point of time owing to the lack of generation e.g. Pluggable Electric Vehicles (PEV), Heating, Ventilating and Air-Conditioning (HVAC) loads. Uncontrollable loads are those to be operated at that time and the customer cannot postpone itto some other time. The importance of DSM increases when intermittent sources such as Photo-Voltaics (PV), wind generation etc are integrated to the power system [18]. If the penetration of these intermittent sources increases, which in the current scenario arising due to environmental considerations, the controllability of generation will be reduced and the system operators will be left with the only other option of controlling the loads.

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With the DSM technology associated with smart grid the MG controller is open to an option of controlling the loads also (apart from generation) for economic operation. The generation is optimized with the objective of minimizing the cost of generation, while loads are optimized with objective of minimizing the inconvenience caused to the customer due to shifting of loads (DSM). The inconvenience caused to the customer is depended on the duration of shifting, customers preference etc, and it can be modeled as a mathematical function depending upon the type of load. It is to be noted that the inconvenience caused is a human feeling and it vary from customer to customer, so it is not possible to represent exactly in a mathematical form, but it is possible to have a comparative measurement. In the case of an industrial or a commercial MG the inconvenience may be directly related to cost or any other physical quantity.

4.0 GENERATOR/LOAD ECONOMICS

In general, cost of the generating units can be modeled as capital cost, maintenance cost and operating cost. Capital cost depends on the power rating of the generating unit, maintenance cost depends on power rating or energy generated or both, operating cost usually depends only on the energy generated or in other words it is the fuel cost [20]. So the total cost can be given as,

$$C = C_c(P^{rated}) + C_M(P^{rated}, P, t) + C_O(P, t) \quad ....(1)$$

Where, C_C, D_M, C_O are capital cost,3 maintenance cost and operating cost respectively.

4.1 Conventional Generators

Cost of conventional generators such as thermal, diesel etc. can be modeled as a quadratic function [20].

$$C = aP^2 + bP + c \quad ....(2)$$

Where, a,b,c are constant for a generator.

4.2 Solar/Wind Generation

For solar and wind generation there is no fuel consumed so its operating cost is zero, but it will have capital cost and maintenance cost. Maintenance cost for wind generation will be higher than that of solar because of moving parts. And Maintenance cost for solar panels is very small and it is usually neglected.

4.3 Energy Storage Systems

There are different types of storage system, pumped storage, battery, super-capacitors, etc. In storage systems there is no use of fuel so there is no fuel cost. Only capital and maintenance cost will be there. Storage efficiency of the system is to be accounted in the cost function. Battery can be modeled as shown below, which will be almost similar for all other storage systems [21].

Capital cost is given by,

$$C_{capital} = C_P P^{rated} + C_Q Q \quad ....(3)$$

Where, Q is the energy capacity of the battery, and are specific costs.

Maintenance cost is given by,

$$c_m = c_1 P^{rated} + c_2 P \quad ....(4)$$

Where, P is the charging/discharging power. c_1 and c_2 are coefficients.

c_2 can be calculated as,

$$c_2 = \frac{Q}{N \times C_{capital}} \quad ....(5)$$

Where, N total number of cycles the battery can charge and discharge, specified by the manufacturer.

State Of Charge (SOC) is the measure of energy contained in the battery. It is given by,

While charging,
SOC at nth interval of time

$$SOC(n) = SOC_{initial} + \eta_c \sum_{i=1}^{n} P_i \times t_i \quad ....(6)$$

While discharging,
SOC at nth interval of time

$$SOC(n) = SOC_{initial} + \eta_d \sum_{i=1}^{n} P_i \times t_i \quad ....(7)$$

Where, η_c & η_d are charging & discharging efficiency respectively, P_i and t_i are power and time duration respectively of n^{th} ime interval.

4.4 Inconvenience Function

As mentioned in section 3 inconvenience caused to the customer can be modeled as a polynomial function or a discontinuous function of the shifting time depending upon the type of load. As an example for HVAC loads: if the load is interrupted for a small interval of time it won't create much of inconvenience to the customer but if it continues a long period, it will be too much of inconvenience. So inconvenience function for HVAC can be modeled as a 2^{nd} degree polynomial. In general, inconvenience function can be modeled as a 3^{rd} degree polynomial assuming there is no loads with discontinuous inconvenience function.

Inconvenience caused due to shifting of l^{th} load by st_l interval of time is given by,

$$I_l(st_l) = A_l st_l^3 + B_l st_l^2 + C_l st_l \quad ....(8)$$

Where *A, B, C* are constant coefficients.

5.0 OBJECTIVE FUNCTION

Minimize,

$$F(P, st) = W_1 \sum_{i=1}^{T} C(P_i, P_{gi}, t_i) + W_2 \sum_{l=1}^{L} I_l(st_l) \quad ....(9)$$

$$\sum P_i + P_{gi} = P_{Li} \quad ....(10)$$

$$P_{min} \le P \le P_{max} \quad ....(11)$$

$$st_{min} \le st \le st_{max} \quad ....(12)$$

Where, P_i is vector with power generated by all units in i^{th} time interval, W_1, W_2 are the weighting coefficients, T is the total number of time intervals, t_i is the duration of i^{th} time interval, L is the total number of loads st_l is the duration which l^{th} load is shifted .

6.0 CONCLUSION

In this paper, optimization strategy for microgrid incorporating DSM is proposed. Since the objective function contains non-continuous functions it is required to use heuristic optimization techniques.

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