Power Distribution in Smart Grids with Renewable Energy Sources

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***Abstract*—We describe the development of a smart grid installation that manages power distribution in a network of distributed generation units (an apartment complex, for instance). Fro simplicity we assume that the complex consists of a small number of apartments (actual size can be several hundreds) whose primary source of power is solar energy harnessed through solar panels. The secondary sources include power received through transmission lines from power stations based on coal, gas, nuclear and hydroelectric energy etc. We aim proactively distributing the power optimally between the units that have excess and shortage of power by running distributed algorithms that employ linear programming models based on the Network-flow problem. Optimal distribution entails ensuring minimal power losses during transmission.**

Keywords—Distributed System, Power Gird, Smart Grid, Renewable Energy, Transmission, Distributed algorithms, Network-Flow problem,

I. INTRODUCTION

An electric power grid is used for moving electrical energy from one place to another. Moving energy involves: 1) Transmission - where electricity is moved from generating site such as a power plant to an electrical substation over long distance high voltage transmission networks, 2) Power distribution - where electricity is moved from the substations to individual consumers over medium distance medium voltage networks. The entire network involved in delivering the electricity is combinedly referred to as an "Electric grid". These electric grids were conceived more than 100 years ago, when electricity needs were simple. These grids provide limited one way interaction and that makes it difficult to handle the raising demands of the 21st century. For example, the fastest-growing sources of renewable power. Wind, solar and geothermal resources are usually located in remote places, where much of the electricity is generated, while most power demand is in urban areas. The electric grid system has difficulty integrating variable sources of power like wind and solar energy on the grid.

Smart Grids introduce a two-way dialogue where electricity and information can be exchanged between the utility and its customers. It uses the power of technology and computers to help the electric grid respond digitally to the changing demand. This technology provides great benefits including automatic rerouting when equipment fails or during outages, detection and isolation of outages before large-scale blackouts, quick and strategic recovery after an emergency etc. Smart Grids also take advantage of customer-owned power generation systems (including large-scale renewable energy systems) to produce power when that is not available in utilities. It will provide grid operators new tools to reduce power demand quickly when wind and solar power drops. Conversely, it can provide more energy storage capability to absorb excess wind and solar power when needed, then release that energy later.

A program named Net Metering for consumers that generate their own power at home, which is using a rooftop solar power system or a small wind turbine, is also provided by Smart Grids Technology. Net Metering program involves the use of a smart meter that records the power flows back into the grid as a credit. Customers can accumulate this credits and get paid for excess power generation using their home power generators. Extensive research is happening in the area of integrating renewable energy resources in Smart Grid systems. [1], [2], [3], [4].

An interesting challenge in advancement of smart grid technology is efficient distribution of power in smart grid systems integrated with renewable energy. In this paper, we propose to develop a feasible distribution strategy to meet the day to day demand and supply needs of every unit within the network optimally.

II. DESCRIPTION

This paper mainly talks about how a utility can balance the supply and demand of power between houses, power plants and the renewable distributed systems. The balance of power includes the production and demand of renewable energy. The distributed system challenge we are aiming to solve in this paper is the management and efficient usage of the "reverse power flow" that can occur during the middle of the day from areas with large amounts of distributed solar panel units. When people go for work, residential electricity demand is low and the generated excess electricity feeds back to the grid through the transformer. Similarly during nights, when the wind flow is high and the demand is low, the power generated is sent back to the grid. The distribution networks in electrical grids are traditionally not designed to accommodate distributed generation. Increasing distributed power generation units is causing profound changes for distribution system operators in planning, operation of distribution networks. In this paper, we propose a electrical distribution network planning mode where energy is distributed in order to meet demand, to satisfy the operating constraints and to minimize power-loss costs. We develop algorithms to generate networks to choose from a set of feeders, the units with excess power, to meet the demand of other houses that are in need of power. Our project is mainly focused on utilizing distributed systems concepts in formulating the network planning model that accommodates two-way power flows. We limit our scope by not considering the flickers, the capacity of wires and difficulty in integration of the distributed generation units. In this paper we consider the individual house hold units as distributed power generation units. We assume that these units have storage devices and can transfer electric energy directly without having the interaction with substations. Our considerations include: 1) Houses that deliver more power and the power plants act as feeders, 2) The efficient way of transferring excess power along the transmission lines and 3) The shortest path for power transfer. This network planning model in electrical distribution can be solved using network flow linear programming model and nearest-neighbour algorithms. We plan to provide an implementation by collecting data from real-time and simulating it through software.

III. Related Work

A number of studies on the construction of power distribution system planning in real environment have been reported. For example, Ranjan et al.[5] described the algorithm for obtaining the optimal feeder path and the location on minimum loss criterion. As the cost is proportional to the distance between each unit, the problem of minimizing cost reduces to that of minimizing distance. If we consider a non-linear objective function for a large scale distributed system, Bhowmik et al.[6] also provides an algorithm to determine how many number of units that are feeders are ideal along with their locations and routes. These papers come up with algorithms to distribute power in a unidirectional grid where the energy to consumers is only provided by the grid. These algorithms and conclusions on distribution network planning are not applicable in a distributed generation environment.

SEIA et al.[7] describes how solar photo voltaic cells can be used by distributed generation unit owners for subsidies. Whenever there is some excess power generated in homes, they can be sold for subsidies, while if there is power shortage from the grid, alternate source of power could be drawn from solar photovoltaic cells. The substations in grid could maintain storage units and smartly manage the distribution of this power along with the power from the main source - power plants. In [8], Akindele Aroge talks about how the smart grid aims to make renewable energy integration in Nigeria feasible using several technologies and approaches that include demand-side management, storage, distributed generation and transmission technology among others. Our approach mainly focuses on scenarios where owner is willing to distribute the solar power to other homes, instead of selling for subsidies.

For solar panel transformer in power distribution system, Awadallah et al.[9] presents a study on the concerns from electric utilities in respect to operation of power transformers under reverse flow conditions via simulation and experiments. Specifically, in order to connect several solar panels into a distributed system, it is mandatory to integrate solar panel generators with transformers. Also, in Awadallah's other work[10], his team presents an investigation on the impact of solar panels on the power quality of distribution networks. We assume that future technological advancements may resolve such issues in integrating grid and the power from distributed generation units. Our approach also works best for power distribution among off-grid distributed generation units.

EPAct 2005[11] talks about the potential benefits the distributed generation units offer to electric system planning and operations. The study describes that electric utilities can use power from distributed generation units to reduce peak loads, to improve the power quality and to improve the overall reliability of electric systems. This study also suggests that state and regional electric resource planning processes, models and tools should be modified to include distributed generation as potential resource option, which can be accomplished by having a model or methodology to estimate benefits using distributed generation units. In this paper we aim to come up with a model that can be extended to substations in the current grid architecture to utilize the benefits of power from distributed generation units. We consider a small subset of distributed generation units - house hold units and the challenges involved due to variations during operation (impacted by weather) in order to come up with an algorithm which solves the demand-supply problem with minimal power losses by utilizing the energy from house hold units. The challenges with variations in energy generation could be solved by using distributed data exchanges between smart installations at each of these entities.

IV. Design

Given a framework in which we have h_t houses, at a given point in time, there would be h_d houses that are in need of power (i.e. have a deficit of power) and h_s houses that have a surplus of power. The rest of the houses would neither have a deficit nor a surplus. There would be connections between houses in the form of power lines that would facilitate power transmission between them. Loss of power through the power lines due to transmission would be directly proportional to (a) the distance between the houses, and (b) the amount of power being transmitted. Our objective is to design algorithms that would transfer power from the ones that have a surplus to the ones that have a deficit in a way so that the power loss due to transmission between the houses is minimized and every houses power needs are met with.

Initially, the houses of the three types would be identified: (1) those that have a deficit of power, (2) those that have a surplus of power, and (3) those that neither have a deficit nor a surplus of power. In the next step, the houses that have a deficit would be notified of those that have a surplus through message passing. For a particular house that has a deficit, once it knows of all those that can donate power (the ones that have a surplus), it would run a distributed algorithm that employs linear programming models [12], [13] to identify the optimal transmission routes and the corresponding amount of power to be transmitted along each route so that the transmission loss in minimized.

It can be shown that our problem reduces to a variant of the max-flow (or Network-flow) problem, the solution of which can be achieved by running distributed algorithms for linear programming at each house.

V. Implementation

Our developed algorithm will be implemented on Java. Nowadays, Java language is more likely to be described as

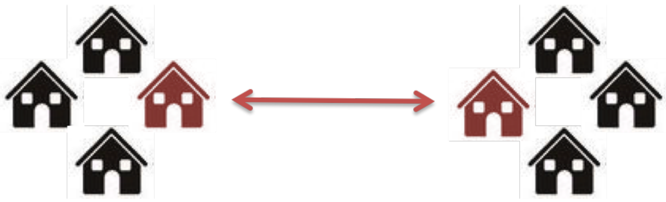

Fig. 1. One to One

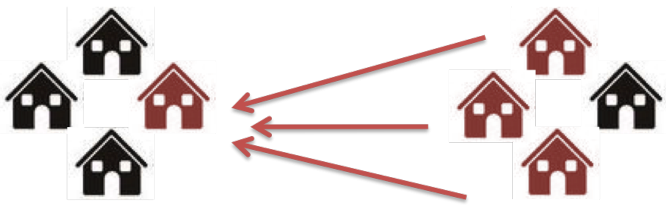

Fig. 2. Many to One

a technology due to the vast development. The compiled Java programs can be run on different machines when simulating electricity markets[14] which we can utilize and run Java programs in all of our test units. Besides, relational databases will be used to store the collecting data and test several realistic problems. Moreover, a linear programming problem based on the network-flow model can be framed to incorporate all the challenges mentioned as constraints, which has an objective function that aims to minimize the net power loss during transmission either from power plant or each unit. We plan to simulate and test the optimal smart grid distribution by using processes as place holders for units.

VI. Evaluation

We consider three situations for evaluating power consumption. In Situation 1, the power consumed by a household is monitored on a monthly basis, i.e. for a given year, the power consumed each month is recorded, and then an averaging is done over all months to compute the power consumed by the household every month. In Situation 2, the monitoring is performed on a weekly basis, i.e. the power consumed each week is recorded, and the averaging this time brings to light the power consumed every week. Finally, in Situation 3, when the power consumption is done on a daily basis, we divide the days into weekdays and weekends since there is a tendency of more power being consumed on the weekends than the weekdays. We then take the average of power consumed by the household both for weekdays and weekend-days.

For each situation, we can have two scenarios. Scenario 1: all households are connected to each other (trivial case), and Scenario 2: all households may not have a link between each other. Thus, in the first Scenario, power can be directly transmitted from the house(s) that has excess power to the house(s) that are in need of power. In the second scenario, however, power may be transmitted through other households depending on the amount of power being transmitted and the cost of power transmission between two houses that already have links between them.

Every scenario will in turn have five cases: Case 1, no house needs power and no house has excess power (which is the ideal case that may never happen in reality); Case 2, only one house needs power and only one house has excess power which it can donate, Fig. 1; Case 3, only one house needs power but many houses have excess power which they can donate, Fig. 2; Case 4, many houses need power but only one house has excess power which it can donate, Fig. 3; Case 5, many houses need power and many houses can donate power. Hence, it is Case 3 and Case 5 which are interesting as these houses that have excess power should transmit power in ways that minimize power loss.

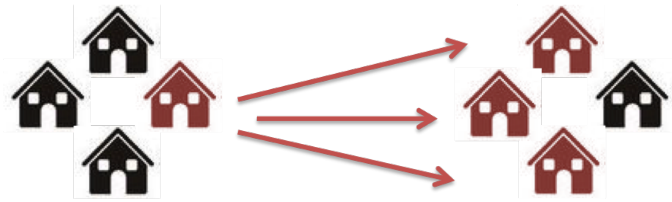

Fig. 3. One to Many

The power consumption data for each house should be generated in real-time, but we assume that working on the averaged and recorded data can suffice for the time being.

VII. Conclusions and Future Work

In this paper we proactively aim to distribute the power optimally between the units that have excess and shortage of power. Our development entails ensuring power losses during transmission. In the future, we will utilize the real-world data to monitor the transmission and distribution of power in order to provide a real-time distributed system for exchanging the power between units instantly[15]. We also propose to develop more reliable and easy-to-monitored interface for users to control the power loss of their units.

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