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Original article

A novel energy management algorithm for reduction of main grid dependence in future smart grids using electric springs

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ABSTRACT

This work presents a new energy management algorithm suitable for micro grids which are dependent on main grids during generation uncertainties in the micro sources. The proposed control algorithm tries to reduce the dependence of micro grids on main grid by adjusting the power supplied to the non-critical loads. The presented methodology is implemented on a micro grid system which consists of renewable power sources and loads, which are broadly classified as critical and non-critical loads. The micro grid system considered for the study is dependent on main grid during generation deficits in the micro sources. In order to implement the proposed technique the non-critical loads present in the system are connected in series with A.C. electric springs. Application of A.C. electric springs in the micro grid system to reduce the dependence on main grid is a different way of looking at the problem of reducing the main grid dependence and is probably the first attempt. The micro grid system considered for the study is designed in MATLAB and simulations are carried out to implement the proposed energy management algorithm.

Introduction

Micro grid is a cluster of controllable loads, distributed energy sources, etc. located in a limited geographical area [1]. These micro grids will be operating in both grid interactive and off grid modes based on the requirement. Due to the growing concerns over environment and pollution, development and use of renewable energy sources in micro/electrical grids is gaining momentum [2]. This momentum gain is also because of the considerable increment in the conversion efficiency of the renewable sources like the solar cells [3]. Whenever renewable generators are used in micro grids there will be uncertainties in generation. This generation intermittence will lead to demand supply gap which has to be handled in order to maintain reliable power supply to the loads present in the micro grid. In some scenarios these micro grids are bound to depend on main/utility grid to meet out the load demand.

In order to deal with the uncertainties of power produced by renewable generators, energy storage facilities have been added to generators in the recent past. These storage devices store the power whenever there is generation sufficiency and release the power to the micro grid during generation deficits [4–6] which means that power supplied will become certain to an extent. So by developing storage facilities in micro grids the uncertain nature of the renewables can be handled and hence the dependence on the main grid will reduce to a considerable extent making the micro grid more autonomous. Apart from introduction of storage to the micro grids another energy management technique called economic dispatch considering the renewable power uncertainties has been developed in [7]. The methodology implemented in [7] uses stochastic programming to schedule the renewable generators based on the generated power and supplies loads accordingly. In order to reduce the overall cost of natural gas and electricity in a building and to rely more on renewable energy sources a stochastic methodology is presented in [8]. The work presented in [8] considers the varying load as well as uncertainties in power generation and schedules the resources. For a grid interactive micro grid which has high penetration of renewable energy sources, an energy management scheme which schedules the available renewable energy sources and demand side resources has been presented in [9]. According to the power produced by the PV arrays and forecasted load a different energy management technique which will be useful for effective coordination of renewable energy sources has been proposed in [10]. The energy management scheme proposed in [10] tries to improve the penetration levels of the PV generators considered for the study. The proposed technique has

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been demonstrated on a house hold micro grid consisting of PV panels and energy storage devices.

By looking at the articles, [4–10] it can be understood that by developing storage facilities in the micro grids as well as by effective scheduling of generators and demand side resources there can be efficient usage of energy in the micro grids. Hence a micro grid which is grid interactive will consume less energy from the main grid during generation deficits if the available resources in the micro grid are properly planned.

Apart from the methods discussed in the articles [4–10] autonomous scheduling of generators based on the load demand has been presented in literature. Based on the available load data from the grid and probable availability of the generated power scheduling of generators is reported in [11]. Going ahead to the smart grid using communication systems online scheduling of the power generating stations has been presented in [12]. The methodology projected in [12] requires communication infrastructure which in turn communicates the existing demand and based on the same generation can be scheduled. So by proper planning of the generation resources present in the micro grids demand supply gap can be minimized to possible extent and hence the main grid dependence can be reduced. It is still a challenge task for the engineers to plan the generation scheduling if most of the generators used in micro grids are renewable.

Demand side management is one of the techniques used in electric grids to reduce the demand supply gap. In order to optimally plan the demand side re-sources the authors in [13] used the game theory approach to re-schedule or plan the non-critical loads. The approach presented will reduce the energy consumption pattern of the consumers which will also benefit the utility in maintaining the demand supply gap. To solve the problem of demand side management certain other optimization tools like the binary particle swarm optimization were also used in the literature [14] which will be useful again to reduce the demand supply gap in the electric utilities. Going a little ahead with the demand side management the author in [15] differentiated between the industrial, commercial and domestic consumers and performed optimal load allocation using game theory approach which is different from that presented in [13,14]. Further in smart environment a real time demand response model which is capable of scheduling the non-critical loads of domestic consumers using automation equipment has been proposed in [16]. This proposed methodology considers the real time energy costs and schedules the flexible loads accordingly.

As similar to the articles [4–10] the articles presented in [11–16] also try to reduce the demand supply gaps in the micro grid to possible extent. Using such methodologies in grid interactive micro grids there will be reduced energy consumption from the main grid during generation deficits in the micro grids.

Looking at the literature and articles, [4–16] reduction of energy consumption from main grid as well as Effective energy management in micro grids can be achieved by different methods viz. Generation scheduling, Demand side management, etc. This paper presents a different Energy management methodology for grid interactive micro grids to reduce their dependence on main grids. The proposed methodology uses A.C. electric springs for effective management of energy in the micro grids during generation deficits, which is probably new.

The concept of A.C. electric springs (E.S) was first proposed in [17]. The electric springs are analogous to mechanical springs and are categorized as input control devices unlike the conventional FACTS devices which are output control devices. In order to evaluate the performance of electric springs a comparative study is made with the STATCOM, which is an output control device [18]. In the study performed it is found out that electric springs as an input control devices provide better voltage regulation than the STATCOM which is path breaking. Going a little ahead on the application of electric springs the authors in [19,20] developed a smart methodology to reduce the battery storage requirement and also to reduce the power drawn from the supply system in future smart grids during generation uncertainties. The authors in [19] have proved that usage of electric springs reduces the battery storage requirement by 50% in comparison with the usage of output control devices like the STATCOM. Whereas the authors in [20] present different cases and proved that using electric springs there will be considerable reduction of power drawn from the supply system as well as the battery in comparison to its absence.

Further to provide better voltage regulation and to improve the voltage profile for the critical loads in grid system as well as the authors in [21–23] used electric springs to counter the voltage fluctuations caused by the renewable energy sources. Also electric springs are used in distribution systems to reduce the power imbalances [24] i.e. they will be useful in reducing the imbalances in the distribution lines which in turn reduces the power losses caused due to the imbalanced lines. Hence looking at the literature on electric springs [17–24] it is clear that electric springs have been implemented for wide range of applications but not used in grid interactive micro grids for effective energy management. The work presented in the article not only focuses on energy management in micro grids but also tries to reduce the energy consumption from the main grid during generation deficits in the micro grids.

Systems modeling and basics of electric spring

In order to reduce the main grid dependence of micro grid during uncertainties in the power generation of the micro sources a new energy management algorithm has been proposed. The proposed energy management algorithm schedules the non-critical loads based on the requirements and make them consume less power by using A.C. electric springs. To test the robustness of A.C. electric springs in doing so a micro grid system which has two load centers, two renewable sources and a main grid interconnection point has been considered. The considered micro grid structure has loads distributed in the micro grid which are away from the intermittent power sources and connected through distribution lines as shown in Fig. 1.

The micro sources considered for the study can only generate full rated power which will be able to feed the critical & non-critical loads as well as the system losses only. In other words there will not be any power left out to supply the main grid or to store it. Hence during generation uncertainties the considered micro grid system is bound to depend on main grid in order to meet out the load demand. The distribution lines used in the grid system are designed strictly following the X/R ratio which has to be in between 2 to 8 for a distribution line [25]. The specifications of the micro grid system are as presented in Table. 1.

The micro grid as shown in Fig. 1 consists of critical loads, non-critical loads and other components as represented and will operate at a frequency of 50 Hz, 1 phase. Critical loads are those types of loads which are essentially sensitive loads and it is necessary to supply uninterrupted power at rated voltage. Non-critical loads are those types of loads which can bare larger voltage fluctuations, say 20% from their rated value. The non-critical loads considered in this study are different from the ones presented in the literature. In literature non-critical loads are those types of loads where they are completely shut down whenever required to achieve demand supply balance. An example of the non-critical loads considered in this study are the newly developed LED lighting system which can operate at a voltage tolerance of 20% without considerable change in the illumination level [26]. Some other examples of non-critical loads can be water heaters, space heaters and lighting