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An intelligent load manager for PV powered off-grid residential houses

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ABSTRACT

This paper proposes a management system based on certain rule set implemented by Modified Mild Intrusive Genetic Algorithm (MMIGA) that will optimize the load allocation to match the house owner affordable solar system inverter. The algorithm optimized load allocation in real time in both sufficient and insufficient supplies of energy. A daily load discrimination profile is first established followed by the development of priority matrix for the respective time of the day; MMIGA is then used to intelligently evolve a sequence of bits, which are then implemented by the hardware while observing certain set of rules. The result shows that about 98.88% allocation was obtained in the sufficient case scenario while 99.84% allocation was achieved in the insufficient scenario. The proposed algorithm meets the objective of being cost effective, smart, simple to use and can be severally applied to different load profiles.

Introduction

The building sector represents one of the largest potentials for energy efficiency and reduction of greenhouse gas emissions. The intelligent use of load and its optimal management is one of the major concerns of utility managers, providers and consumers of energy. Load management in the general sense is the process of balancing the supply of electricity on the network with the electrical load by adjusting or controlling the load rather than the power station output. It is also considered as a set of objectives designed to control and modify the patterns of demand of consumers. It allows limiting or shifting peak load from on-peak to off-peak periods. This can be achieved by direct intervention of the utility in real time, by the use of frequency sensitive relays triggering circuit breakers, or by time clocks, or by using special tariffs to influence consumer behavior.

However, in solar photovoltaic power system, the concept of load management is viewed from the perspective of controlling the load to ensure that the insolation over a period is able to carry the load. Also, the storage system is put into focus. The storage cannot make infinite amount of energy available to the load, thus acquired and available energy must be utilized in the most efficient way possible. This gives credence to research efforts towards developing automatic systems suitable for direct load control, with the goal of making loads active and intelligent.

In a solar photovoltaic power system, a major goal of load management is to ensure that the more critical loads are operated at the expense of the less critical loads and that the storage (battery) is protected from excessive discharge (Groumpos and Papergeorgiou, 1991). Therefore by definition, load management in solar photovoltaic power system is a strategy that involves manipulating the controllable loads to favorably modify system load curve in correspondence to the economically available generation (Groumpos and Papergeorgiou, 1991). This implies that, load management is a mindful maneuvering of the consumer load profile to improve system's efficiency. Research efforts have focused on development of automation systems to improve household load management.

Various techniques have been used for studying and development of different load management strategies such as the use of data mining approach in the development of an energy management system for a naphtha reforming plant (Velazquez et al., 2012), the use of SCADA based software where set points of various subsystems are optimized in real time by means of an integrated systems approach (Du-Plessis et al., 2013; Cristian-Dragos and Adrien, 2012), supervisory strategy with the help of fuzzy logic and graphical methods (Zhang et al., 2012), multi-objective genetic algorithm approach in which the time allocation of domestic loads is optimized within a planning period, the use of an optimization energy system model such as the Integrated MARKAL EFOM System (Fehrenbach et al., 2014) and multi-period gravitational search algorithm techniques (Marzband et al., 2014).

It has been demonstrated that effective load management has positive correlation with energy efficiency and electricity bill. A multi-objective genetic algorithm was used to solve a multi-objective model to optimize the time allocation of domestic loads within a planning period of 36 h, in a smart grid context by Soares et al. (Soares et al., 2014).

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In their work, the management of controllable domestic load was used to minimize the electricity bill. Economic potential for thermal load management with virtual power plants consisting of micro-cogeneration plants, heat pumps and thermal storage within the residential sector was a concern in Fehrenbach et al. (2014). An expert Energy Management System (EEMS) for optimal operation of wind turbines and other Distributed Energy Resources (DERs) in an interconnected micro-grid was a focus in Motevasel and Seifi (Motevasel and Seifi, 2014) with the objective of finding the optimal set points of DERs and storage devices, in such a way that the total operation cost and the net emission are simultaneously minimized. Faxas-Guzmán et al. (Faxas-Guzmán et al., 2014) has developed priority load control algorithm in order to provide a better energy management efficiency that can guarantee energy supply for the critical loads in a standalone PV system. The implementation of this algorithm showed that it is capable of increasing the reliability of the system and the end-user satisfaction. Energy management for a standalone hybrid system that involves wind/PV/battery/fuel cell was proposed by Feroldi et al. (Feroldi et al., 2013). In their work, an optimal sizing methodology based on genetic algorithms was designed for standalone system. Similarly, Wang et al. (Wanga et al., 2011) proposed a topology and energy management strategy of a standalone hybrid PV system, which can solve the over-current problem of the storage battery, and verifies the effectiveness and feasibility of the energy management strategy. The results of their work showed that constant-voltage and current-limited control of the battery are realizable. It was also revealed that battery does not only work in optimal charging and discharging state, but also satisfies the energy storage requirements of the system. In the same manner, Urtasun et al. (Urtasun et al., 2014) developed an energy management strategy for a standalone system in which the battery and the diesel generator are centralized while the loads and the PV generators are distributed and are all connected to the grid. The developed energy management scheme simplifies the complex system in a cheaper and more reliable manner. The strategy also optimizes the efficiency and operating life of the diesel generator. However, Chauhan and Saini (Chauhan and Saini, 2014) are of the opinion that more research and efforts are required to further improve batteries' durability and performance with a focus on lowering their cost.

The use of energy management in building applications has also been reported in the literature. Zhang et al. (Zhang et al., 2012) present an energy management strategy for a commercial building (supermarket application) with the objective of reducing the electricity bill and the CO_2 emissions of the building, using photovoltaic (PV) and storage systems. Their simulation results using economic and ecological indicators revealed that the energy bill cost and the CO_2 emissions were reduced with the proposed energy management scheme. Figueiredo & Martins (Figueiredo and Martins, 2010) were concerned with Energy Production System Management (EPSM) of a building which allows the incorporation of a complete set of renewable energy production and storage systems (Figueiredo and Martins, 2010). They also presented a Building Automation System (BAS) where the Demand Side Management (DSM) is fully integrated with Energy Production System. Similarly, Multi-objective Genetic Algorithm (MOGA) was developed by Pervez et al. (Pervez et al., 2013) to achieve energy efficiency and management in a building. This allows energy saving while achieving a high comfortable environment. A novel strategy for Building Energy Management System (BEMS), which efficiently controls energy flows in a building so as to minimize the total cost of energy for a finite period was proposed by Kang et al. (Kang et al., 2014) The Demand Response (DR) event during the period was also considered.

However, none of the aforementioned studies take into consideration the initial economy of household owners. In developing countries, it is almost a common issue that most households with medium income earners, having interest in the use of renewable energy system as an alternative to epileptic power supply, hardly can afford the required size of solar power inverter system required to power their residences. This inability requires the development of simplified and cheap technologies that are able to match the power provision with the economy of house owners. This current work therefore proposes the use of Modified Mild Intrusive Genetic Algorithm (MMIGA) for intelligent load management of PV powered off-grid residential houses. This intelligent load management system is capable of maintaining the maximum limit of energy consumption within the economic capability of the house owner.

Proposed load management scheme

The frame of operation of the proposed system is illustrated in Fig. 1. It consists of an appropriately/affordably sized inverter system, maintenance free deep cycle battery storage system connected to a bank of solar panel through a solar charge controller. The inverter systems generate the AC and pass on the output to the load through the intelligent load manager (presented in this paper), which produces the load profiles based on certain criteria as obtained and made available by

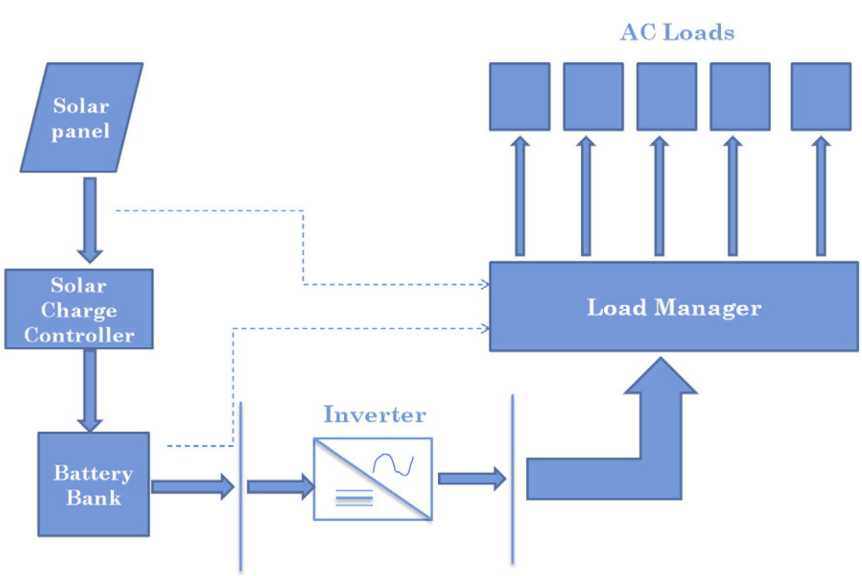

Fig. 1. Architecture of the scheme.