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Industrial demand side response modelling in smart grid using stochastic optimisation considering refinery process

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ABSTRACT

Demand Side Management (DSM) scheme in smart grid technology provides a broader vision of the electricity consumers to participate in power management in the future era. Both residential and industrial sector are active consumers of electric power, in which industry sector are the major consumers of electric power, globally. In this proposed work, demand response modelling scheme for industrial sector is done using Resource task network (RTN) scheduling process and stochastic dynamic programming. The model is designed mathematically and for validating the results practical field data from refinery plant is used. The DR scheme proposed is a new intelligent model for industrial domain with practical approach. The scheme exhibits the refinery processing tasks for scheduling the peak loads by considering the important schedulable tasks in the unit such as distillation unit and other units which involve maximum power. Day ahead pricing scheme is considered for scheduling the loads to shift the demand from peak to non-peak periods. Different pricing schemes are also considered for comparison. The DR problem was mathematically modelled using stochastic programming through minimisation of objective function with set of industrial based constraints. The results are obtained using GAMS solver and Gurobi optimizer in Matlab. By this scheme the shifting of peak hours at different tasks level in the building establishes a reduction of 6.5% cost reduction. The DR scheme proposed is validated with practical results which exhibit to shift the demand from peak to non − peak periods, hence reducing cost.

1. Introduction

In the near future, the energy sector at the global level is set to move towards an intelligent modern power grid. In this growing smart grid landscape, Demand Side Management (DSM) is proclaimed as a major dimension of the future power supply. The conventional electric grid exhibits stability with one way power flow between the utility and the consumers [1]. The construction of new power plants can be curtailed in the coming decades, by bringing in smart grid technologies which thereby reduces CO_2 emissions. Smart grid in the building division offers an incredible open door for enhancing the power quality issues and unwavering quality of energy sources due to the possibility of decentralization of demand supply matching using DR and decrease of transmission losses [2]. DSM plays a major role by providing consumers with an opportunity for reducing the electricity usage [1–4] by shifting from peak hours to non-peak hours or rescheduling the loads. Balancing the electricity supply and demand has always been an underlying challenge in smart grid solutions. Demand Response (DR) plays a key role in DSM for balancing the demand and supply [3–5]. Successful smart grid deployment can be brought in globally by efficient design of DR programs [6].

According to the survey done from US energy report in 2014 [7] the share of electricity consumed by residential consumers was 22% where by the industrial consumers targeted up to 32%. To choose a DR model and to implement the scheme, the effectiveness increases by considering the scope of consumers that are involved in it. In accordance to the global report from Industrial energy agency [7,8] three major sectors like residential, industrial and commercial sectors are the domain where the DR schemes can be applied excluding the transportation sector [6–10]. Apparently, designing of efficient DR program in domestic areas is comparatively easier compared to other sectors. Moreover DR schemes applied in this sector should understand that all the consumption patterns are different based on categories of domestic users like short range, long range consumers and real world mixed advancing and postponing users. This set of users infers its consumption attention depending on current, past and future periods whereas short range consumers include the perception about the energy price based on the current time only. At

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present, many research works have been carried out on designing DR approaches with different intelligent modelling targeting the residential consumers [1–5]. However industry is the major consumer of electricity. Industrial plants are high energy consumers and handle higher peak loads. Globally [6–11] industrial sector accounts for a greater proportion of economy. Therefore there is a greater need for developing successful DR programs and to implement DR for industrial facilities. Different energy savings measures have been followed for buildings by developing economic viable policies like renewable energy sources is explained in the work [12]. Further the analysis of importance of energy saving strategies by developing an optimisation model is formulated in [13]. The work proposed in [14] exhibits a series approach of energy efficient improvement method carried out on specific buildings in Serbia by different measures considering various household scenarios. Similar analysis is done in [15] by developing energy saving methods with the installation of automatic temperature control system for Greek buildings. All the approaches emphasise on the importance of energy efficient approaches at different sector at a global vision and so the need of DR measures is required for better energy saving programs at the next level approach.

Thereby these programs initiated in industrial sector promote reliability of power systems besides reduction in energy costs. Compared to residential consumers there are many issues in planning DR scheme for industrial sector like scheduling pattern of entire manufacturing process. Many plants require monitoring of loads in a time frame of milliseconds and there are security concerns which require careful handling [16,17]. Therefore proposals of new intelligent DR systems considering the above facts can improve reliability of the system in industries. There are important tasks and issues for raising DR for industrial domain compared to residential domain. The purpose of developing DR programs in this domain targets on global economy in electricity market. As per the statistics, the industrial domain occupies 32% in consumption [18].

- The industrial domain process considers many raw material resources, intermediate sources like gas and water along with the electricity resources.
- Furthermore, industrial process is a real time domain where satisfying the real time needs is a difficult task and building DR programs is important.

The implementation of successful DR schemes is challenging and difficult compared to residential sector. Utmost care is needed in implementing DR schemes in industry for the above reasons dealt with. Many industrial processes are sequential and therefore loads cannot be rescheduled at random. Further industrial processes are real time and therefore a mismatch between supply and demand can have serious technical and financial impacts. However, designing and developing new intelligent DR methods can increase the reliability and efficiency [19]. Developing new DR methods can benefit the power utilities and exhibit optimal solution of DR to shift the loads from peak to non-peak hours. Very few research studies and reports exhibit the expediency and asset of DR in the industrial domain. In Refs. [20–22] the authors had dealt with different smart grid DR approaches for industrial domain and explained the overall analysis of DR scheme. In Ref. [21] the paper explains the DR techniques involved to reduce the total energy costs considering few industrial plants as a survey. In Ref. [22] the author clearly explains the features and the barriers found in implementing DR scenarios in industry facilities mainly in California region. The work mentioned in Ref. [23] elaborates the need of DR model using genetic algorithm for controlling peak demand level with energy efficiency considering a general case study of residential buildings. The case study explains the thermal control architecture of shiftable loads like air conditioning loads. In paper [24] the authors proposes a new model for industrial demand side management considering cement industry by using best behavioural scheme model with tariff schemes. The work mentioned in Ref. [25] the author proposes game theory based DR energy management scheme using punishment mechanism for industry facilities. The considered industry for the proposed model in Ref. [25] is refrigerated warehouses. In Refs. [24,25] the authors have implemented different mathematical approaches for reduction of the cost for industrial domain considering different industries. In paper [26] the work is done based on wastewater treatment facilities using DR scheme, concerning a particular sector for load shifting and opportunities of DR in California. In the same aspect, paper [27] exhibits new industrial opportunities with DR scheme for optimizing operations. In the work proposed in Refs. [27,28] the author elaborates the feasibility, importance and facilities of DR scheme approach in a general manner in the industrial sector. The studies and reports mentioned in Refs. [25–28] describes different schemes in a general fashion to implement DR scheme in industrial sector. Moreover, the drawback found in the earlier studies does not impose any specific DR based algorithm [17,24–28] for industrial domain.

Conventional studies in the past [29–31] implementing architecture for industrial domain, do not consider some of the major smart grid components for demand side management like pricing schemes for user interaction. Further in Refs. [31,32] the authors have proposed DR architecture for industrial plants and specifically none of the studies has proposed a particular DR algorithm in general considering the schedulable and non schedulable tasks. In Refs. [33,34] the authors have enunciated the application of DR in different sections in industry domain as in cement and refrigerated systems. The work exhibits a general outlook of DR perspectives on the industry and further mathematical modelling and design were not exhibited at a practical situation. The work mentioned in Ref. [35] explains the need of demand response and various load patterns impact on industrial and commercial consumers. The analysis is done with critical pricing scheme on Korean market. The system does not depict any generalized scheme for DR exhibiting the smart grid features. In paper [36] complete assessment of DR management is clearly mentioned analysing the methodologies that can be proposed in the future. The work in Ref. [36] proclaims the need of DR applicability in various sectors. According to survey done [36] the industrial sector analysis of DR scheme is important at the global electricity market to match the need of economy. The work proposed in Ref. [37] portrays the DR assessment model as a case study in Germany. The REmix model is designed for the analysis. The work generalizes the need of DR assessment in developed countries at energy market level. New models or algorithms have not been proposed for industry consumers. In summary [27–39] the studies focus mainly on some specific task or application and failed to incorporate the major smart grid factors like dynamic pricing scheme in future to implement DR algorithm. Thereby in this work a new intelligent DR model is developed using resource task network (RTN). The model is analysed using real time data from the refinery plant unit, an industrial building. The scheme consists of dynamic hourly price schemes. The scheduling problem of the refinery unit is tackled using RTN under energy constraints. RTN process model is used to develop DR model since it exhibits multiple states and can be coupled with many constraints for industrial process. The proposed work in this paper contributes on DR scheme for industrial domain considering the basic units incorporated in a real time refinery process. The model is done based on real time price based DR scheme for industrial facilities. The process is done by scenario based stochastic dynamic programming arriving at an objective function with a set of constraints. The set of constraints have been articulated based on scheduling and non-scheduling tasks [38] of industrial facilities by Resource Task Network (RTN). The DR problem consists of scheduling the tasks such that the objec-