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An ant colony system based control of shunt capacitor banks for bulk electricity consumers

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ABSTRACT

The present work focuses on the formulation of an optimization algorithm based on Ant Colony Search (ACS) technique operational from a Blackfin DSP microcontroller platform. This intelligent algorithm enables switching of appropriate Shunt Capacitor Banks (SCBs) in installations of bulk consumers of electricity to improve their power factor. The application is mainly targeted on cold storages, rolling mills, traction substation and steel plants in India, where SCBs are installed over a long period in an unplanned manner. Unawareness of the impact of energy savings coupled with the fiscal incapability of these users make them unable to install costly power electronic devices for p.f. control ACS based embedded controller is sensitive to unpredictable load changes and selective capacitors switching cause optimal VAR control with minimum stress to the system. Employing the distributed computational model based on ACS becomes an ideal tool for the combinatorial optimization problem to select a best combination within a bank of varying sizes and varying status signifying dynamically changing search space. This low cost device will reduce the penalty billing of consumers by improving the p.f. and improved metered reading. The use of this device will lead to permeation of technology to the strata which needs it most making energy management possible without any human intervention.

1. Introduction

1.1. Brief background of the problem

Optimizing the reactive power injection is an important aspect for the electric power system's economical and safe operation. Reasonable distribution of reactive compensation capacity in the form of switched capacitor banks, static var controllers is the precondition of realizing voltage and reactive VAR controlling. It can reduce the power loss, improve the power factor and improve the voltage quality, and is helpful for improving the stability of the system. Conventionally, Static Var Compensators (SVCs) have been used in conjunction with passive filters at the distribution level for reactive power compensation and mitigation of power quality problems. SVCs using shunt capacitor banks are installed in substations near the loads are economical reactive power compensators with fast switching speed using current limiting reactors which minimize the switching transients [1]. This switching strategy of shunt capacitor banks at the consumer end will help the consumer and utility simultaneously keeping the VAR requirement from the utility to the minimum. With an improved p.f. and voltage profile, in a dynamically changing load environment by utilizing the available resources (i.e. SCBs) an efficient utilization of electrical energy is possible. Transients generated due to switching of capacitor are difficult to analyze using phasor analysis or other simplified analysis due to system frequency dependencies and non-linearities [2]. The high inrush currents can cause damage to the capacitors of the capacitors bank and weld the contacts of the switch together. The problems of the capacitive inrush currents and ways to reduce the magnitude of the inrush current are major concern during switching of capacitor banks [3]. The process of optimization of reactive power compensation using shunt capacitor banks is a non-linear integral programming problem [4] dealing with the control of dispersed variables [5].

1.2. Relevance in the Indian electricity distribution system

The electricity consumers connected to the Distribution System to the State Electricity Boards in Hooghly and Burdwan district of West Bengal, India comprise of rolling mills, cold storage and

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furnaces with dynamic load pattern. Lack of awareness of energy savings and inadequate finance make them unable to install costly thyristors or insulated gate bipolar transistor (IGBT) based reactive power devices. Several industrial visits to Traction Substations, Steel Plants have ensured the need of a low cost, intelligent and robust power factor control device. For bulk consumers of around 500 kVa, penalty due to low power factor have been imposed and therefore the must convenient solution for them is to use SCBs. It has been also endorsed by the State Electricity Board that a large number of small scale industry consumers do incur heavy penalty losses as they fail to install costly thyristors or IGBT based reactive power compensating devices. According to the surveyed data, in Hoogly District, West Bengal, a distribution system is connected to 60 MVA load and 65% of 348 bulk consumers have not installed any facility to improve the system power factor. At least 113 of these 226 bulk consumers are charged penalties, for their inability to keep power factor within acceptable limits, totaling to Rs. 678,000/- per month. Among the rest, 35% of the consumers, majority has resorted to static VAR compensation techniques which however has resulted in over compensation related problem.

The present scenario of load forecasting suffers from the disadvantage that it considers the load pattern over a period of time. In due course of time this load pattern changes and so does the load forecast. Hence such a method of Static Var compensation using shunt capacitor banks suffers from an inherent drawback of not being able to supply required var with changing load pattern. Thus selection of those shunt capacitor banks that would contribute for a present var requirement without injecting excessive leading var ensures better control.

It is found that for a small value of imbalance, a surplus reactive power can cause an unacceptable variation of voltage level and erodes the absorbing reactive power reserves of rotating units and also increases line losses. If such a localized voltage problem persists the sustained over voltage may lead to insulation failure. It is therefore necessary to accurately meet a particular var requirement by an optimized combination of capacitor banks ensuring better control and would prevent the consumers from incurring large amount of penalties [6]. The algorithm that has been studied which can appropriately address this varying VAR profile by selecting the optimum combination of SCBs is Ant Colony System (ACS). ACS as proposed by Dorigo [7] is inspired from the self-organizing and co-operative behavior of real ants by using a chemical called pheromone. Ants use an indirect form of communication called stigmergy that enables them to find the shortest path between the food source and their nest. ACS based methods provide some distinct advantages like positive feedback, distributed computation, which ensures faster operation as in the present case which is in the range of few milli seconds.

The effectiveness of the algorithm lies in successful identification of the combination of shunt capacitor banks whose capacity is equal or near equal to the reactive power demand. This however depends on the value of the *N* number of individual units of different ratings (i.e. capacitor banks) installed in the premises of the consumer. With the high value of *N* the search space also increases and the use of ADSP-BF533 enhances the computational speed of the algorithm resulting in accurate combinatorial selection of shunt capacitor banks. In the present day VAR compensation has emerged from a local control to a global control strategy [8] in the distribution management system (DMS) software. The algorithm developed using ACS algorithm and tested on bulk installation can be extended to capacitor switching for feeder health control in an automated Distribution Management System, using the same optimization technique but different optimized parameters.

2. Selection of optimization algorithm

Optimization may be defined as the science of determining the 'best' solutions to certain mathematically defined problems, which are often models of physical reality. It involves the study of optimality criteria for problems, the determination of algorithmic methods of solution, the study of the structure of such methods, and computer experimentation with methods both under trial conditions and on real life problems. The 1940s and 1950s saw the introduction and development of the very important branch of the subject known as linear programming [9]. All these methods however had a fairly restricted range of application, and again in the post war period methods of wide applicability which did not rely on any special structure in the problem were developed. The latter methods were at first very crude and inefficient, but the subject was again revolutionized in 1959. In the classical way of optimization it is essential to derive the gradient of the function to be optimized and then employ gradient descent or quasi Newton Method. While metaheuristics [10] is a set of algorithmic concepts that can be used to define heuristic methods applicable to a wide set of different problems. The use of metaheuristics has significantly increased the ability of finding very high quality solutions to hard, practically relevant combinatorial problems in a reasonable time. This method do not use the gradient or Hessian matrix so their advantage is that the function to be optimized need not be continuous or differentiable and it can also have constraints. Metaheuristics make few or no assumptions about the problem being optimized and can search very large spaces of solution. It is used for combinatorial optimization in which an optimal solution is sought over discrete search space. Popular metaheuristics for combinatorial problems include simulated annealing by Kirkpatrick et al. [11], genetic algorithms by Holland et al. [12] and ant colony optimization by Dorigo [7]. Simulated annealing method is easy to code, capable of dealing with arbitrary system and guarantees finding of an optimum solution on the other hand genetic algorithm is modular, supports multi objective optimization and the concept is easy to understand. Ant colony optimization has an advantage over simulated annealing and genetic algorithm approaches that is when the graph of the search space changes dynamically, the ant colony algorithm may still run continuously and adapt to the changes in real time. Hence ant colony optimization may be considered for problems with hidden dynamics. ACS handles history in a very flexible way by storing the already visited nodes details in its memory for future reference. This is very much suitable for our problem while optimizing with regard to the parameters defining a changing search space.

3. Brief introduction of ACS and its implementation in the present objective of var compensating strategy

ACS is a metaheuristic search algorithm which was started from the Ant System (AS) proposed by Marco Dorigo in 1992 is inspired from the self-organizing and co-operative behaviour of real ants by using a chemical called pheromone. Ants use an indirect form of communication called stigmergy that senses the intensity of pheromone which enables them to find the shortest path between the food source and their nest without using any visual cases. Real ants are capable of finding the shortest path from food source to their nest, without using visual cases, but by exploiting pheromone information. While walking, real ants deposit a certain amount of pheromone trails on the ground and each ant probabilistically prefers to follow a direction rich in pheromone, deposited by earlier ants rather than a poorer one as in Fig. 1

In recent years, the interest of the scientific community in ACS has risen sharply. In fact, several applications of ACS to a wide range