SMART GRID OPTIMIZATION USING ADVANCED CONTROL SYSTEM MODEL

[1]Er. Rahul Gupta,[2]Er. Bharti Sood,[3]Er. Abhishek Kumar Chambel
[1]Assistant Professor,[2]Assistant Professor,[3]Student
[1]Electrical and Electronics Engg., [2]Electronics& Communications Engg., [3]Electrical & Electronics Engg.
[123]Maharaja Agrasen University, Baddi, Himachal Pradesh,India

Abstract:In this paper, an advanced model predictive control (AMPC) is developed for smart grids. For economic and environmental problems of smart grids, complex system based approach is applied in modeling and computing on the optimization at different levels of grid.

***Index Terms* - Dynamic model, simulation, control, smart grid**

I. INTRODUCTION

In this paper, a general framework is being proposed for solving the environmental/economic problem of smart grid by advanced model predictive control (AMPC). An advance complex system based approach is applied to the smart grid modeling and computing on the optimization by use of game theory and classical methods at different levels. Smart grids are advanced grids which integrate renewable energy resources (RES) with non-renewable resources. These grids are complex in nature, efficient, reliable and have large energy storage. The earlier model developed of predictive control is open type but smart grids model also uses closed loop control system.

II. SMART GRID AND COMPLEX SYSTEMS

A. Smart Grid:

Smart grid is an electrical grid which is intelligent in order to predict and respond to the behavior and actions of all electric power users that are connected to suppliers and consumers. These grids can be used to provide maximum efficiency, reliability, economic value and sustainable electricity services. Smart Grid has three goals. First one is to enhance the reliability, second one is to reduce peak demand and third is to reduce total energy consumption of electrical markets. To achieve these goals, number of modern technologies have been developed and integrated in the complex electrical network. A Smart Grid integrates advanced sensing technologies, mathematical control methods and integrated communications at different levels .

The Smart Grid should have following 5 characteristics:

1) Attack resistance;
2) Consumers market motivation;
3)Self-healing;
4) High quality factor;
5) Generation and storage options.

Smart grids are composed of electrical and electronic devices from smart and intelligent meters to solar inverters of electrical substation with sensors on power lines. Electricity can be produced by different processes: from the thermal plant and stable production of a nuclear plant, to the storage via electric vehicles, and integration of renewable energy with non-renewable depends upon environmental as well economic factors. A large transmission and distribution network has been created over the years but it is not mastered nor optimized. Therefore, a reliable and sustainable model is required to control the working of complex integrated grid.

B Complex Systems:

A complex system is system consists of large populations or variables that are connected in different forms. In smart grid, we define the variables as agents (or collections of interacting elements) that results in global dynamics from the actions of its parts rather than being imposed by a central controller. The study of complex system includes the field of science, engineering, management, and medicine as well. Both natural and artificial systems have characteristics of complex systems. Classical methods fail most of the time in study of complex systems. For example, optimization as in research operation seeks to solve an objective function, often with multiple variables and constraints.

Applying the optimization method in complex systems is almost a tough task because:

1) complex systems have heterogeneous parts;
2) it is hard to find integration of all the variables;
3) even if all variables are included, the computation of complex equation of the objective function will become beyond the computation powers of computers.

Another attempt to understand complex systems include the structural method studies of electrical complex networks. These networks have characteristics which are not easy to be found in simple networks, and thus called complex networks. Complex network theory has become a major interest area in complex system study and provides mathematical tools to understand the model and transfer function of structures of complex systems. The classical modelling and simulation study of Complex systems, as definition, contain multiple parts which interact with each other. In mathematical approach, these parts are modeled as agents and interactions as agent interactions. After abstracting and adding the environment and economic factors in which complex system exists, the model become market based model of the system, which will enable the simulation of the complex system with flexibility and parameters. In agent based models, the validity of the model depends largely on the abstraction of agents, interactions and environment conditions around the agents, during which mathematical tools, such as complex network theory, game theory, etc., provide abstraction methods. There is even development of modeling methodologies with concerning agent based models, such as ASPECS, to facilitate and rectify the model development and interaction.

C. Smart grid with complex systems:

In the previous section, we have discussed the smart grid and complex system with optimization difficulties in complex systems. In this section, we will discuss the complex system mathematical approach on which we try to provide a solution of optimization problems in electrical smart grid. The complexity of electrical networks has been known for long, and research as well as experimental industrial works has been carried out to find effective and economical solutions. However, the efforts are often determined on particular cases, and solutions are, too, specific without any scope for evolution. Among the projected solutions we can mention:

i. *Transmission and Distributed micro grids:* Since a centralized optimization is very costly in terms of time and memory, optimization should be done at all different levels. The micro grids can change the centralized boundary into a distributed interface, therefore optimization can be carried out in a different manner. Thus, calculation benefits in terms of time and memory are important, while ensuring optimal solution at different levels.
ii. *Designing of intelligent network (home automation and SCADA):* Implementing smart devices can better understand the real needs of consumers and markets.
iii. *Energy storage devices*: The energy storage coupled with energy optimization from beginning to end, regulates consumption and clears utilization peaks.
iv. *Market control of price:* when the network becomes intelligent, it is necessary that the consumer prices may also change in order to track the new consumer behaviour.

The future smart grid nevertheless has a defect: the division of levels is based on technological developments and not according to the homogeneity of the sub-components. Therefore, there should be a new subsystem for each new technology, which only complicates the existing power grid problems. That is why we propose in this paper an analysis of the smart grid as a complex system. Like any complex system, the Smart Grid has a large number of various entities interact in a complex network. In order to optimize the entire system, we must observe and study the complex system in order to distinguish the sub-components. Each sub-component is defined by common criteria: interacting elements, greater homogeneity, common or compatible interest and purpose. For example, in a residential area, the various devices of every house want to receive a certain amount of energy. All units are consumer or prosumer, possessing many common characteristics, thus they can be applied in a single optimization algorithm. Local optimal solution is used in the overall system for a communication system that integrates the data exchange between the different components. These standardized data provide transparency between the subcomponents, while ensuring the privacy of the internal calculation. Influences are then reduced to a feedback system to balance the components interactions. This self-regulation provides an optimal solution at different scales.

III. DYNAMIC MODELLING OF INTEGERATED SMART GRIDS AND THEIR PARAMETERS

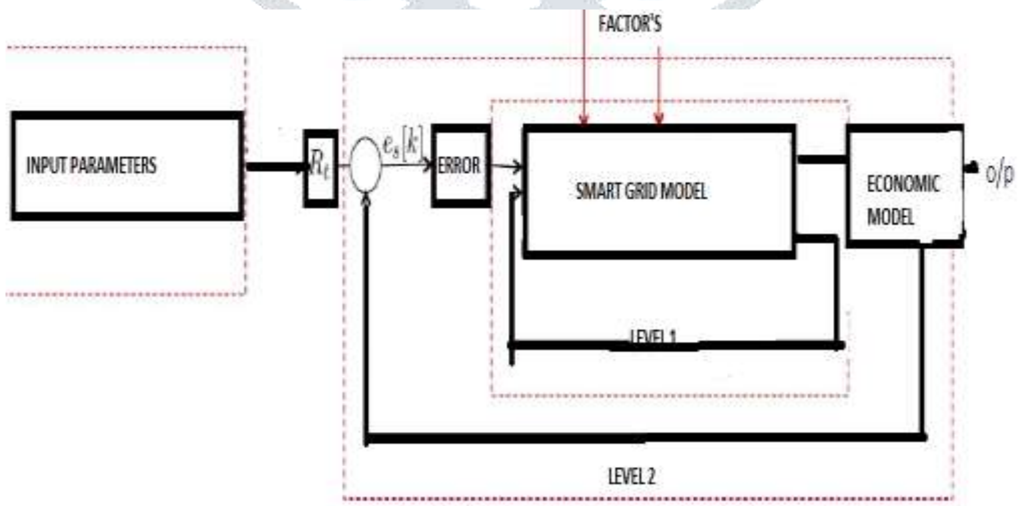

Fig. 1: Fundamental Dynamic Model

Planning of distributed energy resources (DERS) should be done in such a way so that it produces maximum optimization. Basically there are two independent models of smart grids. First one is physical (related to environmental) and other is economical. The physical system is a complex integrated network that consists of power flow through generators to substation by transmission lines. Loads attached to substation results in environmental emissions and study of volatility of price in markets. Secondly, economic system consists of dynamic market prices which vary daily due to agents. The coupling of two models with feedback and uncertainties lead to complexity of system. Therefore, it is important to study the behaviour of overall system that includes the dynamics and their feedback. The research has main consideration on development of fundamental dynamic model that includes generation, demand, pricing, emissions and congestion. The topics which are investigated for dynamic model are mentioned as below.

A Numerical Analysis for parameters of market and grid:

For the study of model of grid with market conditions, balancing condition is required with uncertainties of transmission and generation. Perturbation theory is used for numerical analysis of equilibrium conditions. The market conditions are studied by game theory (part of peA. N-player Game Formulation).

Consider the game to be played by N electrical vehicle owners who decide at all time on the optimal battery level given a utility function encompassing three parameters:

(i) The economical cost or gain of filling or emptying the battery;
(ii) The (psychological) cost of operating on the battery at certain time instants of the day; and
(iii) The disutility for the user to have a nearly empty battery.

For player i ∈ {1, . . ., N},
We denote X(i) t ∈ [0,1]
Its state variable, corresponding to its battery level at time t ∈ [0, T].
We assume that player i modifies X(i)t by a quantity α(i) t dt, at time t.
We also assume that player i consumes a quantity g(i)t dt of energy at time t.
We therefore have the state evolution for each player given by the equation

$$d\ dt(i)\ t = \alpha(i)t - g(i)t$$

(1) where we restrict α (i)t and g(i)t to be such that X (i)t ∈ [0,1] for all t and is uniquely defined. rturbation theory) by concept of closeness of variables

B. *Mechanism of Dynamic model (MDM):*

The optimized model framework developed for dynamic model having uncertainties of renewable energy resources and market demand prices. Stability conditions are analyzed by game theory for energy resources and demand response of market The gradient based method helps to understand the uncertainties in generation, demand, pricing and congestion control.

C. *Design of Control Architecture for Renewable Resources:*

The information of grid can be obtained from different sources like time scales and algorithms (control in nature). Different levels have been given to understand the dynamic behaviour of the model. Level-1 represents the behaviour of smart grid with its uncertainties while level-2 represents the dynamic behaviour of market conditions. Controlling technique is applied to ensure the regulation in frequency having optimal energy. Evaluation of uncertainties with time scales can be solved numerically.

D. *Modelling of Integrated response for Electricity Markets:*

Changes are required in the fundamental operation and planning of integrated Renewable Energy Resources(RER). The fundamental change is mainly done in model of Demand Response (DR) of electricity markets. The demand response can be divided into parts.one is shiftable Demand Response (SDR) and other is adjustable demand response(ADR). Overall market model will be evaluated numerically which also leads to Social Welfare by reducing prices. In addition, survey of demand response by various participants will be included. At present, literature survey on DR, run-time, price control, and economic dispatch is being explored.

IV. A SMART GRID MODEL FOR OPTIMIZATION

In previous sections, after familiarizing with smart grid and complex system, we approached smart grid with complex system point of view. Our observation and discussions prepared us to present the model in this section for smart grid optimization. We analyzed the network structure, parameters and behavior of the smart grid entities. From these data, we defined three sub-components or levels having their own properties and objectives. There are three different levels in model of smart grid and they are: 1) Input level 2) Grid level 3) Economic Model.

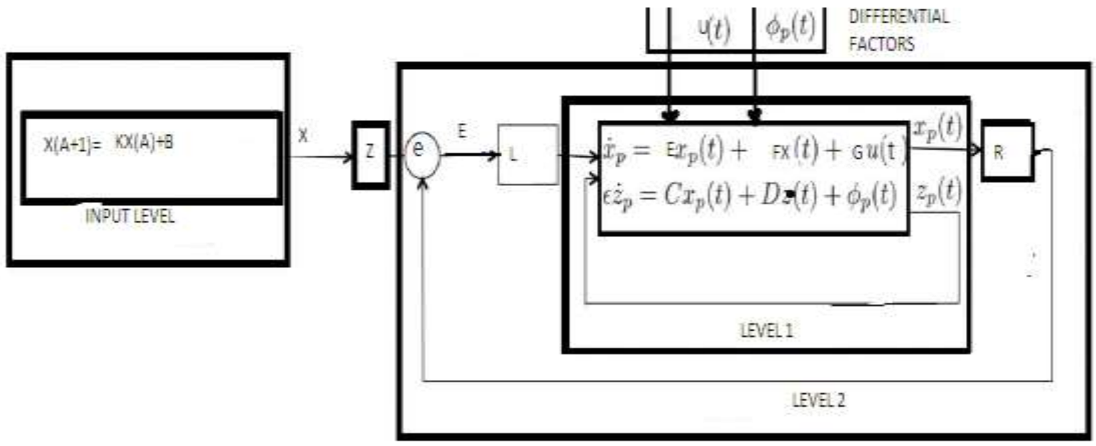

Fig. 2: Mathematical Grid Model

A. Input Level: In input level we insert the parameters which are deterministic in nature. Let us consider the variable x having time constrained factor i.e.: X(A+1) =K*X*(A) + B

Where A is fixed interval of time, B is variable and k is constant

B. Grid Level: In this level, we introduce the evaluate differential factors to solve the grid factors. The differential factors are environmental factors i.e. L, input factor, u(t) is unit factor, ϕ is phase factor of grid. The equations are divide into 2 parts: First one is unit equation and second is phase equation 1 & 2:

$$\dot{x}_p = Ex_p(t) + Fx_p(t) + GU(t) \qquad \text{------ (1)}$$

$$ez_p = Cx_p(t) + Dz(t) + \phi(t) \qquad \text{------ (2)}$$

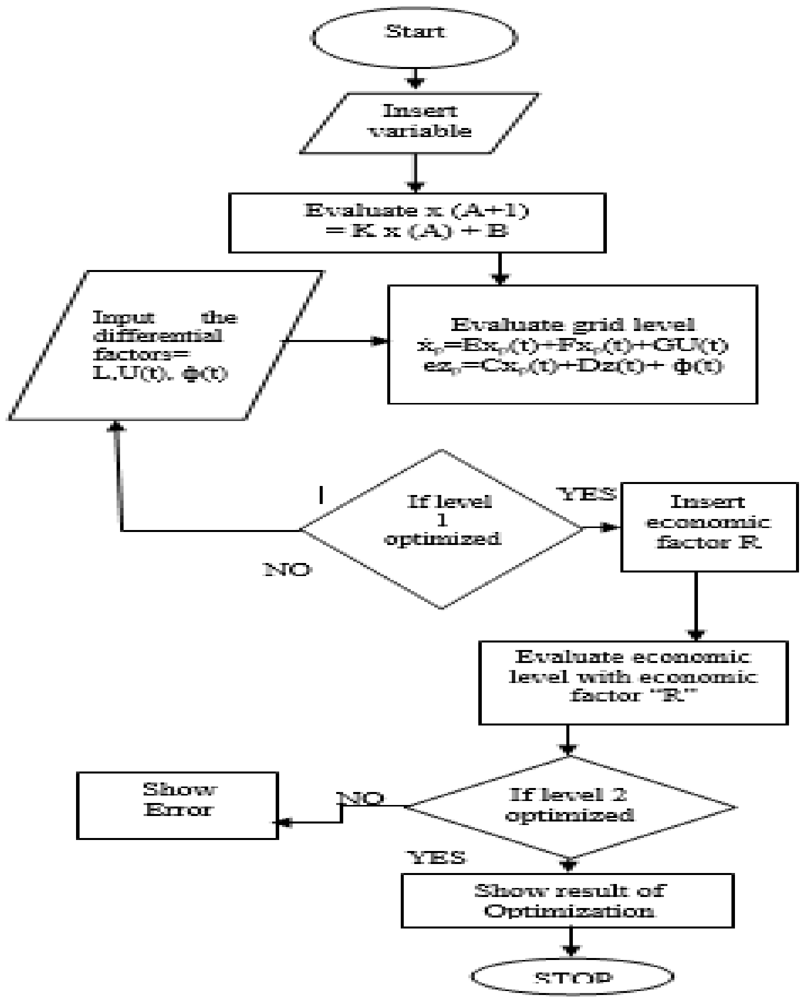

Fig. 3: Flowchart of Mathematical Grid Model

C. *Economic Level:*

This is final level in which we introduce the economic factor to solve the complexity of market values. The economic factors are market based factors which changes continuously i.e. "R" is economic factor which is multiplied with grid level equations

$$\begin{pmatrix} \dot{x}_p = Ex_p(t) + Fx_p(t) \\ ez_p = Cx_p(t) + Dz(t) + \phi(t) \end{pmatrix} * R$$

V. CONCLUSIONS AND PERSPECTIVES

In this paper, we addressed the problem of optimization in smart grids. As smart grid can be qualified as a complex system, classical methods of optimization methods cannot be applied directly due to the computational complexity of equations in terms of time and memory. Since it is complex system, we studied the smart grid from global and local point of views, and were able to find sub-components with common objectives and behaviors. Since each sub-component consists of homogeneous actors concerning the optimization problem, we were able to apply algorithms to achieve the optimization goal. It should be noted that those algorithms work together in different levels to achieve the global optimization. Our approach applies different algorithms and coordinates between them to achieve optimization in smart grid. In addition, it also resulted an approach with flexibility and generality. More generally, we also demonstrated how to solve optimization problems in complex systems. While applying optimization algorithms directly in complex systems is nearly impossible, we should analyze the system and divide them into sub-systems with homogeneous characteristics, then we should apply specific algorithms and coordinate them to achieve global optimization. A general model of smart grid is being developed, which integrates those algorithms. Preliminary tests have shown promises and potential of our approach. Once it is finished, we will validate the model with real world data.

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