ISSN NUMBER (ONLINE) – 2368-1209 & (PRINT) – 2691-5944

Use of 'Intelligent Control' and 'Optimization' in Micro-grid System

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***Abstract*--The use of non-renewable energy is decreasing day by day or in an exponential way to save our earth. Thus, research related to the renewable energy is increasing rapidly. In case of micro-grid, 'EED' mechanism fails to generate high efficiency or is unable to predict the external noise coming into the system. As an alternative, in this research work we proposed a 'Model predictive Controller' using 'Intelligent Control Analogy' that helps to track the output of the micro-grid system. Not only that, both the variability and unpredictability of the renewable energy source can be controlled using the above proposed method. In this scheme, the data are taken from the load and output of the solar energy. Then, using optimizing technique, it has been optimized subjected to the different constraint.**

***Index Terms*--The Intelligent Control, Optimization, Renewable Energy, MPC scheme, Micro-grid**

NOMENCLATURE

Table 1: Abbreviationof the used Notation in this article

Notation	***Meaning***
EMS	Energy Management System
EED	Existing Economic Dispatch
RES	Renewable Energy Sources
NRES	Non- Renewable Energy Sources
MPC	Model Predictive Control
DES	Distributed Energy Sources
MA	Microgrid Architechture
PV	Photovoltaic
GHE	Green House Effect
STLF	Short Term Load Forecasting
MAPE	Mean Absolute Percentage Error
P_{arr}	Power generated by PV Array
Y	Admittance Matrix
P_s	Powe supplied by the Source
E_s	Energy storedin the storage unit
P_{tr}	Power supplied through Transmission line
P_n	Energy absorbed by a node
C_{tr}	Cost Coefficient of Transmission
C_m	Cost for maintenance

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I. INTRODUCTION

If the use of nonrenewable energy is increasing, then the world will become unsustainable. It is observed that, from the year of 2005, the use of green power energy is become very popular as it is very economical. After that the concept of microgrid comes into the picture [1]. Microgrid is a combination of some different module such as energy source, cluster of loads, energy storing units etc. But the problem is that these modules may not be connected with the main grid. If the output of the microgrid is not up to the mark, then the proper designing of controller is mandatory, otherwise the design will not be robust. Use of 'MA' is very flexible and also lighter in weight. There is also an advantage of using microgrid, that is if there is some bigger fault in a circuit is found, then microgrid is getting disconnected and the microgrid is working as an island network. Figure 1 given below represents as hybrid (A.C /D.C) structure of microgrid system. Optimum designing of controller is badly needed to minimize the cost and as well as to fulfill the load demand. Again, the power allocation decision is taken by 'EMS'. Hence there are some procedures to get optimal design is needed. For example,the turn on and turn off time of the switch, how much power to be delivered to the load etc.

Volume 2, Issue 1
https://doi.org/10.15864/ajac.21025

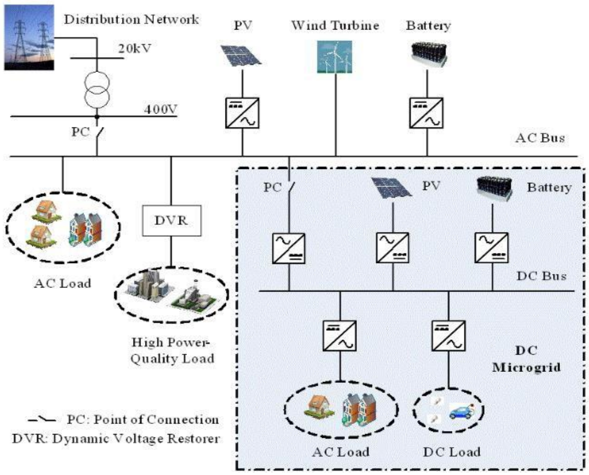

Fig. 1. A hybrid microgrid Architecture

II. Recent trends in Microgrid System: A Literature Review

There are so many research works are already done in this research field. Shahgholian, G. et.al.[3] gives a detail review of microgridsincluding its operation, application, modeling and control. A comparative study is also given in tabulated form. In case of distributed potential formation, the concept of microgrid circuits very important and how it can be used is also described by the authors. The relative stability of the microgrid control circuit is also explained in detail. There are so many types of microgrid are available in the market. Bessa, I.V. et.al.[4] shows how to enhance the sustainability of the 'DC Microgrid'where CPL is generallyconnected.Designing of a hybrid model structure, the tradeoff between cost and reliability is described in detail by the researcher Borhanazad, H. [5]. To improve the structure, optimization technique has been applied. But finally HMGS is considered as a good alternative of optimization process.Driesen, J. et.al. [6] talks about the design of the 'Distributed energy resources'which is very much beneficial for the future research work. A review study has been published in the research work [7]-[8], where the advantages of the 'DES' towards the environments are discussed in detail. This study shows us the dangerous impact on the environment if we increase the use of traditional power plant. The application of 'Distributed Generation' based technologies reduces the effect of 'GHE' also. Bayindir, R. et. al. [9] describes the existing use of different control system-based technique of microgrid through the world. As advantages and disadvantages of all the process regarding the microgrid is given in comparison form, hence it is very much helpful in finding the future research work. On the other hand,Abusharkh, S. et. al. [10] shows how a microgrid system is effective for the generation of the power supply. Some beautiful application of the wind power energy had been depicted by the researcher Díaz-González, F.et.al. [11]. How energy can be stored had also been described in different ways. The consumer always demands the clean and low-cost power supply. Kirubakaran, A. et.al. [12] represents the comparative study related to the different 'Fuel cell technologies' in a proper way which will be guided the researchers a lot. Same concept is also investigated the researcher Mekhilef, S. et.al. [13]. Again Neef, H.J. et.al. [14] explained the concept of hydrogen energy-based technologies used in the microgrid system. Based on the experimental result it was concluded that cost might be reduced with the help of these technologies.Anothername of the microgrid is called intelligent grid. Mittal, A. et. al. [15] describes the benefits and drawbacks of the recent microgrid circuit. Not only that, current microgrid related project throughout the globe has alsobeen discussed in detail. Dohn, L.R. et.al [16] verifies the efficiency of a microgrid that can be used in communication system. In this research article, highly decentralized coordinating scheme are proposed along with the experimental results. Concept of 'Bipolar DC buses' are also given in this section. Lidula, N.W.A. et.al. [17] shows some typical microgrid simulation which are very rare in nature and how synchronization of microgrid test network is generally done with optimum facility is also explained in detail. The source network may be connected in series or in parallel with the microgrid system or can be used as island. Lasseter, R.H. et. al. [18] demonstrated the way to utilize the waste heat from the source and as a result efficiency increases a lot. Application of intelligent control is far better with respect to the traditional distributed control. Two famous internationals standard called "IEC 61850 and IEC 61499" [19] proposes a special technique that has the ability to generate the automatic logic. Hence the flexibility of the automated system has been increased. Ultimately this concept gives the birth of 'Smart grid'. Anyway, in a research article [20], Asmus, P. et.al. describes the various opportunities regarding microgrid system. Hossain, E. et.al. [21] discussed some basic question related with microgrid circuits. For example: Brief introduction to distributed system, Key benefits of using microgrid etc. Not only that, technological gap for connecting the today's world with 'Hybrid microgrid circuit' is found in this research article with proper comparative table. A special class of hybrid microgrid circuit is introduced by theresearcher Khodaei, A. et. al. [22]. In this article, the characteristics of the microgrid circuit is discussed with the help of simulation is depicted in detail. The necessary island requirements and unused available capacity of microgrid circuit is also analyzed in this paper. The process of decomposing 'Optimal scheduling problem' has also been depicted. Finally going through the so many research works, it is observed that there is little bit of technological gap relatedto the 'Island Microgrid' in the sense that, till today the island microgrid are not emerged with the application of controller orno optimization process has been applied. Hence in this research paper, we have tried to fulfill this gap and applied methodology is discussed in the next section.

[1] Novelty of this Research

In general, the island microgrid consist of four modules - 'Load', 'Storage Unit', 'PV Array', 'Thermal Generator'.Thebeauty of this research work is to allocate power individually for each and every energy source in the microgrid in such a way that, the power consumption will be minimized. Our proposed controller is doing this performance with very high efficiency. In order to design 'MPC' we collect real time data which makes the design more effective. To conduct 'STLF', we use the AI-ML (SVM) which is the uniqueness of the design. On the other hand, 'Optimization process' has been applied to make the entire design robust and cost effective.

[2] Real Time Data Collection for the Proposed Design:

In power industries, the 'Load Forecasting' is mainly used for setting up the market price, power scheduling etc. 'Forecastingprocesses 'is used to extract the accurate information from the historic or past load and weather data for future prediction. To implement 'STLF' successfully, two types of approach is generally been taken. Conventional approach (Regression model, Stochastic model, Exponential Model etc.) and (SVM, Fuzzy Logic, PSO etc.).

Table 1: Collected data for the proposed design

Date	Observation Time (In Hours)	Minimum Temperature	Maximum Temperature	Minimum Humidity	Maximum Humidity
07.01.2022	03	11.2	24.3	55	79
11.01.2022	07	09.5	22.7	56	75
19.01.2022	08	12.8	27.6	54	74
28.01.2022	06	18.4	32.0	57	87

The entire procedure of 'Forecasting processes' can be visualized into four parts. Input identification, Pre-processing data, Selection of training set, testing of collected data.
Some weather data are taken for the designing of the proposed system. The table 1 given below is showing the collected data. The above data are collected from the location around Kolkata, West Bengal, India. Now we are going to apply the 'SVM algorithm' on the training data set. This is one kind of regression problem. The main aim of this design is to find the correlation between inputs and outputs. Due to the nonlinear decision boundary, the collected data is mapped into a higher dimension space. Finally, the problem is converted into an optimization problem, where support vectors are defined as the maximum distance between the hyper-planes.

Let (, y_i) be a data point of a training data set and $'T'$ is the perpendicular vector with respect to the parallel lines. Hence the distance (d) between the support vector is mathematically is given by the following equation.

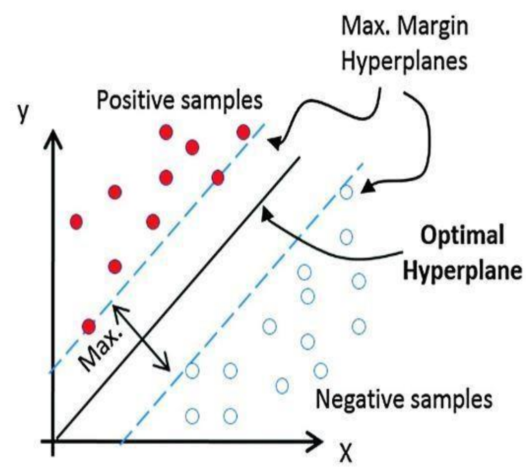

Fig. 2. Linear separation of the collected data

$$d = \frac{2}{\sqrt{\psi.\psi^t}} \quad (1)$$

After applying some approximation to the above equation becomes

$$d = 0.5(\psi.\psi^t) \quad (2)$$

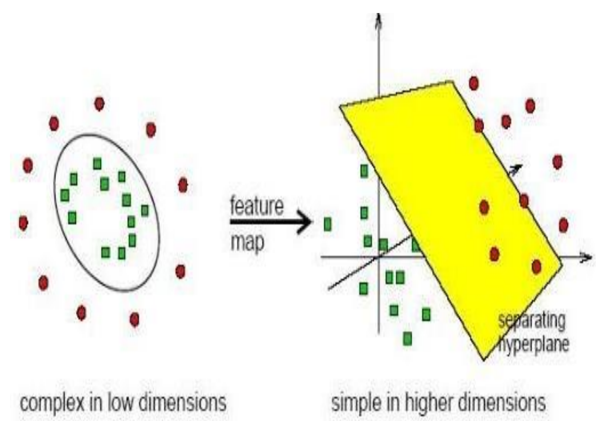

Fig. 3. Proper use of Kernel Function

The above figure 3 is expressing the collected data are linearly separable in higher dimensions whereas in the lower dimension it is complex in nature. There is no such hard and fast rule for selecting a kernel function rather it depends upon the dataset and current situation. Actually, the problem in higher dimension has automatically been solved which is the advantages of working with the higher dimension. The hyper planes with maximum margin are always preferable as probability of error is less.

[3] *PV Array Output Forecast*

Without pollution, PV Array generates electricity. This is why it is called ‘Green Energy’. The exact forecasting of ‘Green Energy’ is quite difficult as both the stability and operating cost may be hampered. Recent trends in forecasting method is found to be evolutionary method. The figure 4 givenbelow is nothing but a pictorial view of a ‘PV Array’.

Fig. 4. A Photovoltaic Array

In order to study a ‘PV Array’, generally four parameters are used. Open circuit voltage, short circuit current, output power and Fill factor.

$$i_{sc}(T) = i_{rsc} (1 + (T - T_0)) \frac{GI}{GI_0} \quad (3)$$

In the above equation, isc is the short circuit current and α represent the specification of the module. The term in the equation (3) GI_0 is denoting the irradiance value of module. Again irsc refers the short circuit current calculated at STP. Here ‘T’ stands for temp in deg Centigrade. Global horizontal irradiance is represented by ‘GH’. Similarly, the open circuit voltage is given by the following equation.

$$v_{oc}(T) = v_{rsc}(T)\ (1 + \beta(T - T0)) \quad (4)$$

In the above equation, open circuit voltage is represented byv_{sc}. v_{rsc}= Ref open circuit voltage calculated at STP. ′β′ represents the module specification value.

$$FF = \frac{v_{pmax} . i_{pmax}}{v_{oc} . i_{oc}} \quad (5)$$

Maximum power that can be generated by PV moduleis given by (v_{pmax} . i_{pmax})

Again, the product of(v_{oc}) and (i_{oc})gives the output power generated at any instant of time.

Let, p_a = Array Power andp_o= ac output power. p_m represents the Power of the PV module ($m_p m_s$)is denoting the number of parallel and series unit,

Then $p_a = p_m m_p m_s$ (6)

$p_o = \eta_{pac} p_a$ (7)

In the equation (7),η_{pac} is the efficiency of ac power of PV module.

[4] *Short term load forecasting using SVM& Modeling of Microgrid*

Here in this paper, we are applying the concept of clustering. The load demand is related with the time directly. The load demand is also disrupted by the time, humidity, temperature etc. The main aim to design the ‘SVM model’ is to recognize the above stated factors. In this research work, a support vector regression model is proposed. The input feature is given in the table 1.

Lagrange multiplier’ can be used to solve the above problem. Using kernel function the original feature space can be shifted into the higher dimensional features. In equation 2, putting the value of $\Psi = \omega$ as a dummy variable, weget the following equation (8). Here the cost function is defined by the parameter′γ′.

$$\begin{cases} \frac{1}{2} . \omega^t + \Upsilon \sum_{i=0}^{k} (\varepsilon_i + \varepsilon_i^*) < 0 \\ y_i - (\omega x_i + b) \leq (\varepsilon_i + \varepsilon_i^*) \\ (\omega x_i + b) - y_i \geq (\varepsilon_i + \varepsilon_i^*) \end{cases} \quad (8)$$

Hence, we conclude thatγ > 0 (9)

The structure of microgrid control circuit is very complex as the control stages are connected at different stages. On the other hand, the controller must have a finite dead time. If the transportation delay is too large, the entire system may not work. Anyway, a controller related to the microgrid must follow the following issue. The power must be controlled. All the load demand must be satisfied at every instant. The compensation of the relative power and harmonic fluctuation must be taken into consideration. Our proposed design related to the microgrid structure includes the following features. Our aim is to develop the ‘MCP -mechanism’ for optimizing the present market cost. Finally using simulation, we prove the validity of the entire design.

Let ‘R’ is the actual value, ‘F’ is the forecasted value. Set of nodes is denoted by ‘V’ and set of edge is denoted by ‘E’.

$$E \subseteq V \times V \quad (10)$$

$$P_{tr} = diag(y_{ij}) \times B' \times \theta \quad (11)$$

In the above equation, Θ is denoting the phase angle. yij = admitance of lineconnecting i th ad j th node and Y is admittance matrix, then

$$Y = B \times diag(yij) \times B' \quad (12)$$

$$P_{tr} = diag(y_{ij}) \times B' \times T^{-1} \begin{vmatrix} Y_{bar}^{-1} \times P_{vbar} \\ \theta_v \end{vmatrix} \quad (13)$$

https://doi.org/10.15864/ajac.21025

$$T = \begin{vmatrix} I_{4\times4} & -1_{4\times4} \\ 0_{4\times4} & 1 \end{vmatrix}$$

$u(k) = (P'_g(k), P'_{st}(k), P'_{re}(k))'$

$\Delta(k) = (\Delta'_g, \Delta'_{st}, \Delta'_{re})$

$w(k) = (w'_l(k), w'_{re}(k))'$

$x(k) = Est(k)$

$$x(k+1) = Ax(k) + B(u(k) + H(\Delta)w(k)) \quad (14)$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{i=n}\left|\frac{R(t)-F(t)}{R(t)}\right| \quad (15)$$

$$P_v = \begin{vmatrix} u(k) + H(\Delta)w(k) \\ w_1'(k) \\ P_n \end{vmatrix} \quad (16)$$

$$J(x,u,w) = \sum_{k=0}^{k-1}\beta^k(p_g(k) - p_r(k) + c_{ptr}^T|p_{tr}(k)| + C_{opmt}^T\Delta(k) + C_{switch}^T(|\Delta(k) - \Delta(k-1)|) \quad (17)$$

Applying the proper approximation,

$x_{mn} \leq x(k) \geq x_{mx}$

$p_{tr}^{mn} \leq p_{tr}(k) \geq p_{tr}^{mx}$

$w_{mn} \leq w(k) \geq w_{mx}$

$p_n = (p_g^{nom}, p_s^{nom}, 0)$

$$diag(u_{mn}\Delta(k)) \leq u(k) + H(\Delta)w(k) \geq diag(u_{mx}\Delta(k)) \quad (18)$$

$c_{ptr}^T\ |p_{tr}(k)|$= cost of power transport

$C_{switch}^T(|\Delta(k) - \Delta(k-1)|)$= switching cost. Start up and shut down cost included in it

$C_{opmt}^T\ \Delta(k)$= Operating and maintenance cost of running machines.

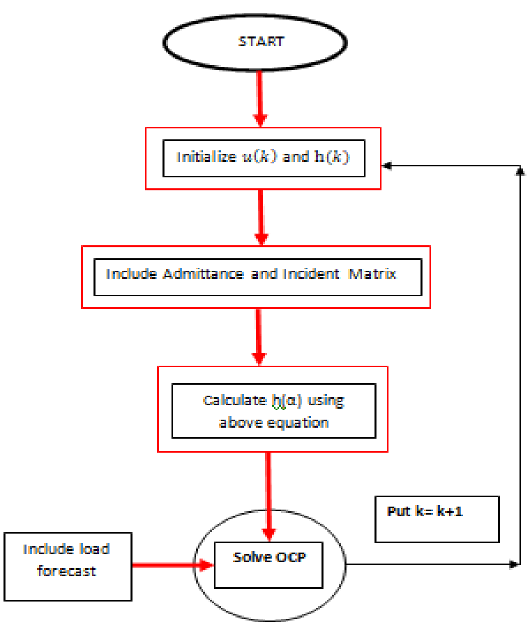

Fig. 5. Flowchart of MPC

In the above figure 5, a flowchart of 'MPC' is shown with a suitable block diagram. The real-world problem is always suffering from some constrains. Sometime constrains may be avoided but it may not be avoided in case of microgrid structures.MPC is such type of algorithm which is able to solve the optimal control problem. In the above flowchart, (k) is the present state at k^{th}sample. Here initially the value of (k) and $h(k)$ has to be initialized. Then the admittance and incidence matrix are included. Then using the above modeling equation, $h(\alpha)$ is calculated. After the problem regarding OCP has been solved. Finally, the iteration occurs for the $(k+1)^h$ sample.

[5] Result of Numerical Simulation

Without using the critical designing of controller, our proposed design is able to satisfy the load demand. It is observed from the simulation that, our design sometimes takes more power from the load but the overall design is robust in nature. In the figure '6', the 'X' axis represents the sampling time in 60 minute and 'Y' axis represents the boundaries

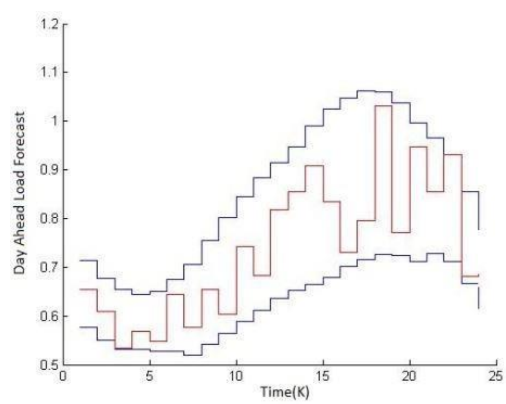

Fig. 6. Load over time with certain boundary

The boundaries are very important as they are acting as a constraint variable.From the above figure, it is observed that, the load is maximum at 18th sample of continuous time and minimum at 6th sample. Both the boundaries are initialized bytheir present state. Anyway, figure 'Y' given below.

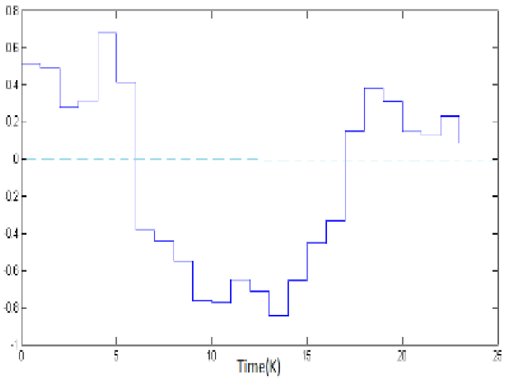

Fig. 7. Optimized control input for the storage unit

As OCP aims to reduce the running cost, the thermal generator was used only for the once time. It is observed from the figure 7 that, from k=0 to 4 and k=11 to 22, the 'RES infeed' is zero. Hence the system is optimized.

[6] *Conclusion*

Here in this research work, initially an 'MPC' is designed based on intelligent control analogy to increase the efficiency of the microgrid system. After that, optimization process is explained considering island microgrid. For the forecasting purpose the machine learning tool like SVM algorithm is used.It is found the proposed design is more economical with respect to the previous design. If we implement an island microgrid using our approach, it can be concluded that the entire design is robust, flexible in nature also. No error will occur in case of load forecasting, if we solve the 'MPC based optimal control'.

Appendix

Appendixes, if needed, appear before the acknowledgment.

III. Acknowledgment

The following is an example of an acknowledgment. (Please note that financial support should be acknowledged in the unnumbered footnote on the title page.)

The authors gratefully acknowledge the contributions of I. X. Austan, A. H. Burgmeyer, C. J. Essel, and S. H. Gold for their work on the original version of this document.

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