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Optimal Operation of Smart Grids Based on Power Loss Minimization Using Distribution Optimal Power Flow Model

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Abstract*— *In this paper a model is provided to reduce losses of distribution feeders using control equipments in Smart Grids. Genetic Algorithm method is used in MATLAB to solve the proposed model. A case study carried out on IEEE-13BUS in order to investigation the performance and feasibility of the proposed model.

Keywords—**Nonlinear programming, smart grid, optimal operation, distribution system**.

I. INTRODUCTION

The issue of smart grid has become a significant part of the power industry in different countries since 2005. This is because governments consider power shortages and increase in consumption as big threats for the economy of their country and together with other challenges such as decreasing greenhouse gas emissions and reducing power loss during transmission and distribution has led to a huge leap to smart grid. Hence, big industrial countries like the US, Canada, China, Japan, South Korea, Australia and EU countries have commenced extensive investigations and different projects regarding smart grids. On the other hand, abundant emissions of pollutant gasses, climate changes, global warming and limited fossil fuel sources have encouraged the power industry to consider reducing pollutant emissions and controlling the limited fossil fuel sources and attempt to make the bed for renewable energy sources and to increase the connection of distributed generation (DG) sources to the power grids close to consumers in order to minimize the loss of energy [1].

Although using distributed generation sources and renewable sources like wind, solar, geothermal and other sources can decrease the aforementioned worries. However, in presence of DGs, issues such as increased complications of Optimal power flow problem and optimal operation of the grid, the type of DG connection, locating and optimal output of DGs will certainly create enormous challenges for distribution system operators (DSO). It goes without saying that one of the fundamental objectives of distribution systems is achieving optimal operation and the main task of DSOs is to balance supply and demand and also consider physical restrictions or economic and security aspects of the grid[2]. Reference [3] considers the smart grid to be maximal use of distributed generation sources in distribution feeders and also increment of consumers participation in controlling and operating the grid. Nevertheless, DSO has different alternatives to create balance between supply and demand, like using DGs and Plug-in hybrid electric vehicle (PHEV) on the demand side. For this reason, coordination and simultaneous connection of DSO and consumers in smart grids requires appropriate bilateral connection facilities and also Advanced Metering Infrastructures (AMI) [4]. Reference [5] Also considers mutual cooperation of IT and communications with power engineering essential in implementing smart grids. Two way connection and AMI using in smart grid clearly is shown in fig.1 [6]. In [7], planning for selection of interruptible loads (IL) is suggested regarding the decrease in received energy from sub-transmission and optimal operation of distribution feeders in smart grids. In [8], a smart grid model with switched capacitor banks and Load Tap Changers (LTC) without DGs is analyzed. Nonetheless, according to the aforementioned items, using DGs will be more efficient in order to decrease distribution loss and received power. In [9], DG modelling of diesel type is presented regardless of pollution emissions, which will not be a suitable model for future given its environmental challenges and the tendency towards smart grids. In a study by Bharathi et.al. regarding the pollution emissions of DGs, the pollution level equation and coefficients of several DGs has been clearly modelled [10].

II. PROPOSAL SMART GRID MODEL

A. Structure of Distribution System

In order to reduce losses in suggested smart distribution grids, besides Distribution Optimal Power Flow (DOPF) according to the aforementioned factors, DGs and control equipment are considered. Among the most significant control equipment, switched capacitor banks (SC) and LTC transformers can be named that in addition to improvement of voltage profile will lead to reduction of losses and eventually

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the reduction of received energy from the substation. According to figure 1, in this paper it is assumed that a mutual connection is possible between DSO and consumers side and also quick control commands can be sent to existing DSOs.

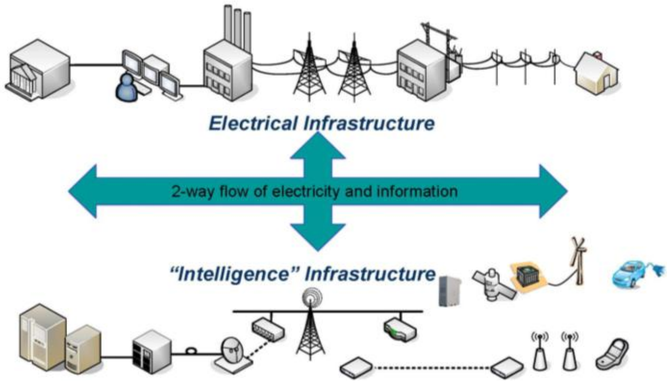

Fig. 1. Two way connection in smart grid[5]

Although capacitor banks, LTC transformers and DGs will technically and economically optimize the grid, they will increase the computational burden and complications in distribution system operation. In the proposed model, as well as considering the mentioned equipment, optimal and hourly operation throughout a day is studied assuming there is unbalanced loading. This assumption will lead the issue of distribution to become a highly complicated mixed integer non-linear programming (MINLP) with high computational burden. Since solving the DOPF throughout a day is essential for the right control command to be implemented, the calculations and time of execution of the optimal operation must be very low.

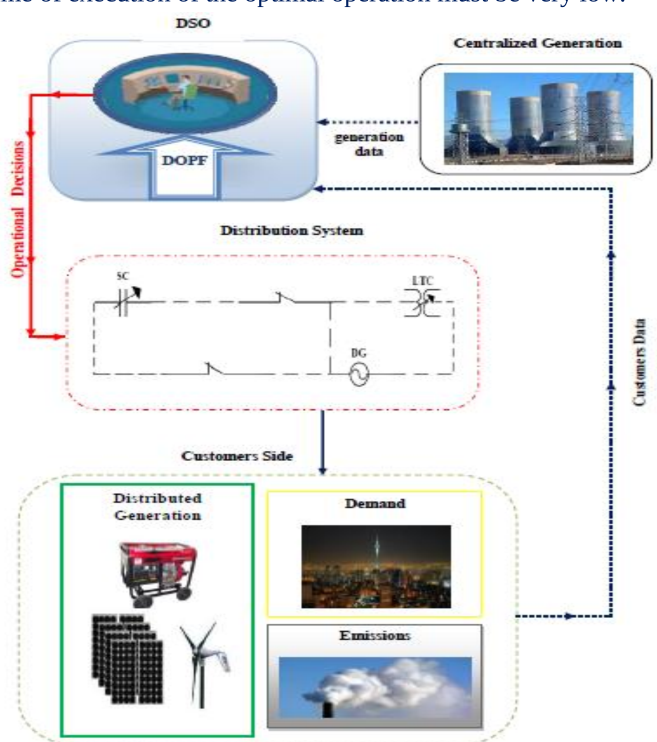

Fig. 2. Schematic diagram of the proposed smart grid

Also considering environmental challenges, the pollution emissions of DGs is taken into account. Figure 2 clearly shows the structure of smart distribution grid and how the optimal operating procedures are done by DSOs and it also shows the transmission of control commands from DSO to control equipment and DG.

B. Mathematical Problem Formulation

The decision variables of optimization problem include LTC and SC position, DG output power and also emission. Hence, the variables are defined as column matrixes in (1).

$$x = \begin{bmatrix} tap_{C,h} \\ tap_{T,h} \\ Pdg_h \end{bmatrix} \tag{1}$$

Where $tap_{C,h}$ and $tap_{T,h}$ are, respectively, tap position of the SC and LTC in each hour and Pdg_h is the active power output in each hour.

The objective function is defined according to decrease in losses, limiting the number of LTCs and SCs switching while considering the reduction of emissions per day. Thus, the initial objective function is formulated as (2).

$$\begin{aligned} J = \ & \kappa \sum_{h=1}^{24} (f_{emi,h}) + \mu \left[\sum_{h=1}^{24} (Pnet_h + Pdg_h - PL_h) \right] + \\ & \phi \left[\sum_{h=1}^{24} \sum_{C=1}^{Nc} \left| tap_{C,h} - tap_{C,h-1} \right| \right] + \eta \left[\sum_{h=1}^{24} \sum_{T=1}^{Nt} \left| tap_{T,h} - tap_{T,h-1} \right| \right] \end{aligned} \tag{2}$$

PL_h is the power losses in each hour. Since the objective function includes four main parts, different segments are introduced with different degrees of significance. These coefficients are κ, μ, ϕ and η.

$f_{emi,h}$ is the emission function represented in [10] is formulated as follows:

$$f_{emi,h} = 10^{-2} (\alpha + \beta . Pdg_h + \gamma Pdg_h{}^2) + \xi \exp(\lambda . Pdg_h) \tag{3}$$

In the above equation $\alpha, \beta, \gamma, \xi$ and λ are emission coefficients and for each DG varies. A method proposed in [11] is adopted in this paper that alleviates the use of integer variables and thus transforms the MINLP into an NLP problem. A quadratic penalty term is augmented to the objective function (4), resulting in the following modified objective function:

$$\begin{aligned} f = \sum_{h=1}^{24} \Bigg[& \sum_{C=1}^{Nc} \left(tap_{C,h} - round\,(tap_{C,h}) \right)^2 + \\ & \left(tap_{T,h} - round\,(tap_{T,h}) \right)^2 \ \Bigg] \end{aligned} \tag{4}$$

Eventually, the general objective function, minimized here as cost function, is shown in 5.

$$obj : \min\{J + f\} \tag{5}$$

The constraints include voltage limitation in the grid and restriction of power flow in each phase. 6 and 7 express these inequality constraints:

$$I_{s,h} \leq I\_\max_{s,h} \quad (6)$$

$$V\_\min \leq V_{i,h} \leq V\_\max \quad (7)$$

$I_{s,h}$, $I\_\max_{s,h}$ are respectively current of the s branch and maximum limited current in each hour.

C. Solution Method

To address the issue of unbalanced loads in the presence of DG, equations related to recursive sweep load (forward-backward load flow) are used in [12] and [13]. In unbalanced grids and also feeders with DGs and LTCs, conventional distribution methods cannot be used. There are different approaches in this regard all of which are based on iteration. One of the best methods is DOPF. This is completely described in [10]. In this part, the mathematical equations of this method are briefly described. Finally, the issue is raised during a day according to the objective function which was mentioned previously. In order to approach this, MATLAB software is used and optimization via genetic algorithm (GA) is considered with a iteration of 100 for better convergence. In (6-11) all equation of this Solution Method is represented.

$$\begin{bmatrix} \overline{V_{l,s}} \\ \overline{I_{l,s}} \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} \overline{V_{l,r}} \\ \overline{I_{l,r}} \end{bmatrix} \quad \forall l. \quad (8)$$

$$A_t = w \begin{bmatrix} 1+\Delta S_t tap_{a,h} \\ 1+\Delta S_t tap_{b,h} \\ 1+\Delta S_t tap_{c,h} \end{bmatrix} \quad \forall h. \quad (9)$$

$$D_t = A_t^{-1} \quad \forall h. \quad (10)$$

In above equation $V_{l,s}, I_{l,s}$ are voltage and current of sending-end. $V_{l,r}, I_{l,r}$ are voltage and current of receiving-end. A, B, C, D are parameters of all transmission series element. ΔS_t is Percentage voltage change for each LTC tap.

For a three-phase tap changer, the following additional equation is used to make sure that all tap operations are the same:

$$tap_{a,h} = tap_{b,h} = tap_{c,h} \quad (11)$$

III. RESULTS AND TABLES

A. Case Study

A case study carried out on IEEE-13BUS test feeder (shown in Fig.3 and number of phases in the feeders are depicted with cross bars) in order to investigation the performance and feasibility of the proposed model. In this feeder test exist two SCs in 611 and 675 nodes and also one LTC between 633 and 634 nodes. Synchronization DG modeled in type of P-Q with 0.85 lag power factor.

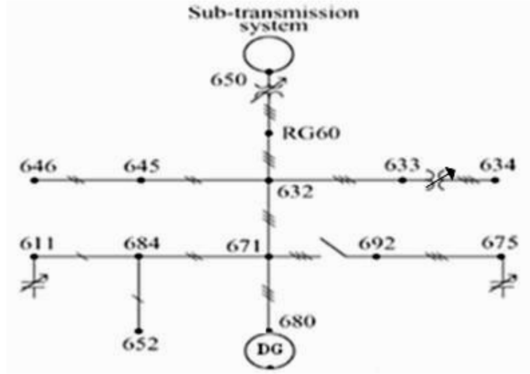

Fig. 3. IEEE 13-bus test feeder

In the equation (3): $\alpha, \beta, \gamma, \xi$ and λ are emission coefficients that provided in table (1). Three phase Load profiles for IEEE 13-BUS test feeder in a day Shown in fig.4. SCs and LTC Specifications respectively represented in table 2 and table 3.

TABLE 1: DG emission coefficients [10]

α (ton/h)	β (ton/MWh)	γ (ton/MWh^2)	ζ (ton/h)	λ (ton/MWh)
2.857	2×10^{-4}	6.49	-5.094	4.091

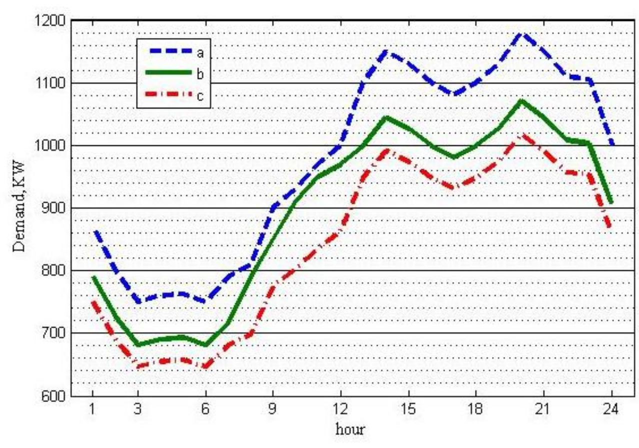

Fig. 4. Load profiles for IEEE 13-BUS test feeder[14]

TABLE 2 : SCs Specifications [8]

NODE NO.	TAP CAPACITY	TAP RANGE
675	100 KVAR	[0 , 5]
611	50 KVAR	[0 , 5]

TABLE 3: LTC Specifications [8]

node position	% voltage change	Range TAP
633 ~ 634	0.315	[-16 , 16]

B. Simulation Results

In table 4 optimal results of operation in 24 hours time-frame are presented. That optimal values Be included, hourly DG output power, LTC tap position (LTC) and capacitor banks tap position (CAP1, CAP2). DG output Varies between 8-196 KW during the 24 hours.

TABLE 3 : optimal results in 24 hours

hour	DG output	CAP1	CAP2	LTC
1	89	4	3	3
2	39	3	2	-12
3	8	3	2	-8
4	51	3	2	15
5	182	3	3	-13
6	179	3	2	7
7	70	4	2	12
8	196	3	3	2
9	32	3	3	9
10	132	3	3	-6
11	111	3	4	14
12	73	3	4	0
13	30	4	4	2
14	125	5	4	-15
15	24	4	4	9
16	120	4	4	2
17	75	5	4	-2
18	66	4	4	5
19	57	4	4	15
20	149	5	5	-15
21	67	5	4	15
22	34	5	4	-7
23	170	4	4	6
24	52	4	4	1

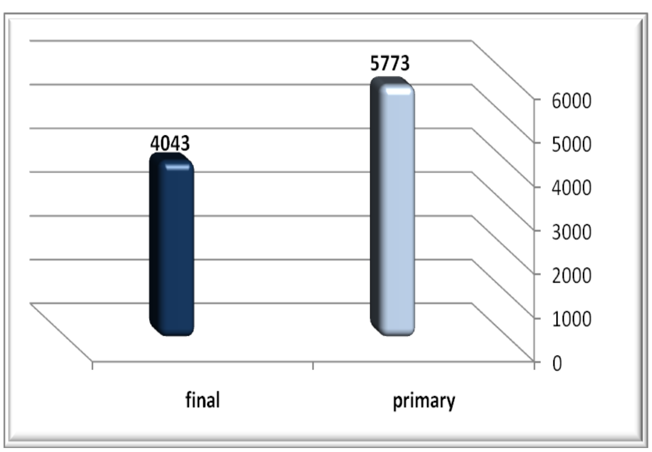

Fig. 5. Total Losses (KW)

Fig.5 is the comparative diagram of total loss in Primary mode regardless of control equipment and DGs, and shows Final mode in presence of DG and control equipment. These results are suggestive of more than 29% reduction in power losses. Therefore, the main objective of this research that is reducing losses has been realized.

Fig.6 is the comparative diagram of energy consumption in primary and final modes that shown Reducing energy consumption in all hours. The following diagram expresses further reduction of energy consumption in peak load hours.

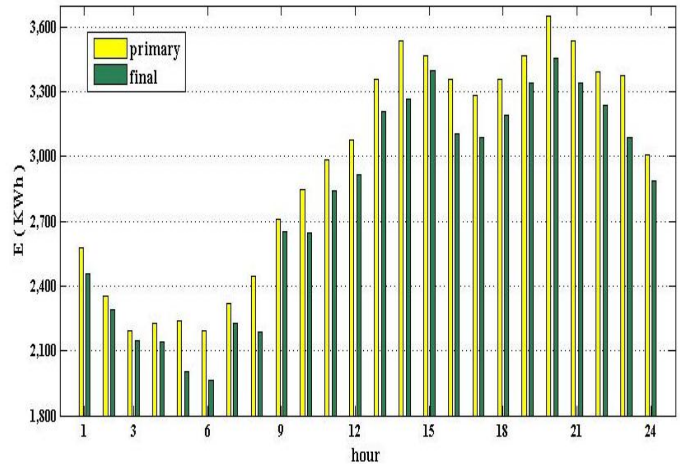

Fig. 6. energy consumption in each hour

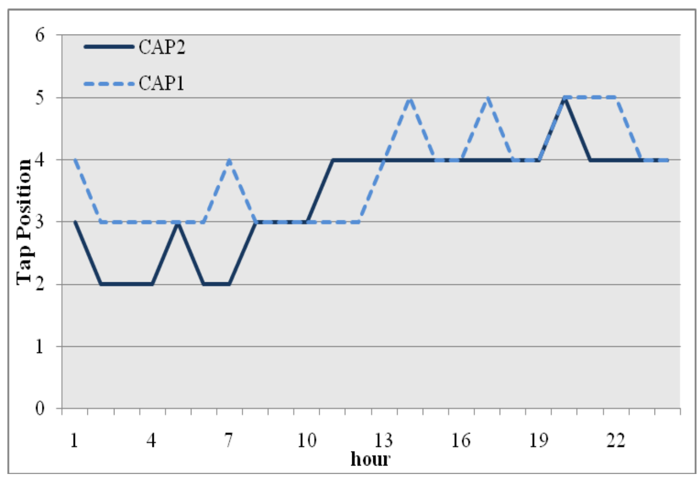

Fig. 7. SCs tap position in 24 hours

The tap position changes during the 24 hours are represented in fig.7. It can be said that the changes of SCs tap influenced by the daily load pattern.

In fig.8 comparative chart of hourly losses are provided. In both cases the Reduction of losses is clearly obvious. But reduction of losses in peak load hours is more clearly.

At the end in diagram 9, the emission of DGs during a daily operation is shown. Note that pollution emissions in specific hours are very high and in another hours that Index are improved.

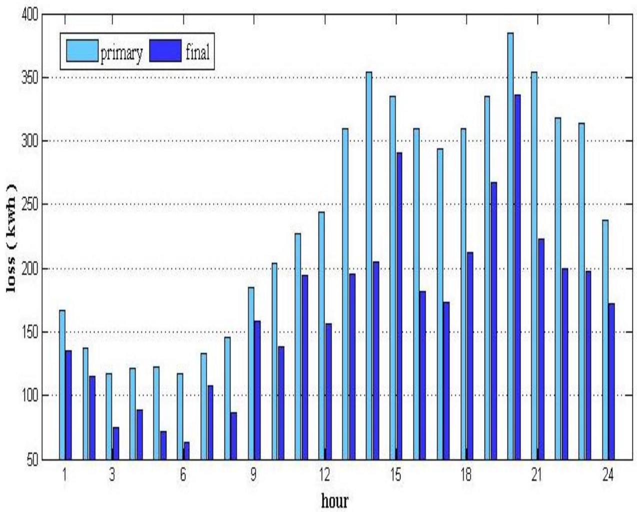

Fig. 8. comparative chart of hourly losses

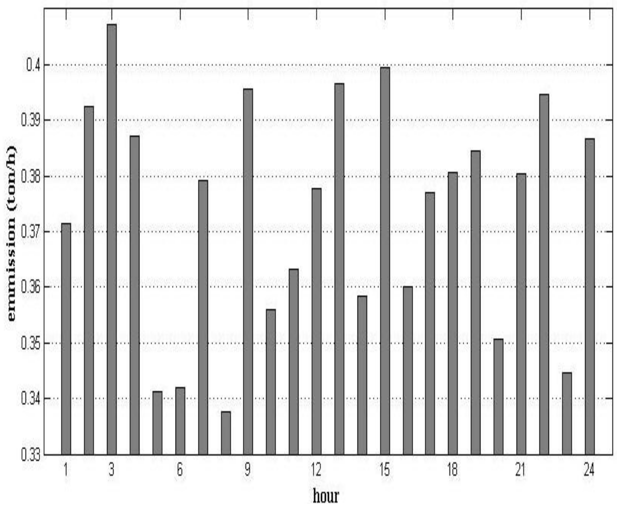

Fig. 9. Pollution emissions

IV. CONCLUSION

By optimal adjustment of the tap position of this equipment and adjusting optimal output of DGs, the smart grid can be operated in optimal and economic status. Also, considering the fact that in future smart grids emissions are seriously accounted for, the effect of this parameter is considered in objective function in this paper with optimal operation of the grid concurrent with reduction of emissions. In this paper, it was possible to achieve optimal grid operation through genetic algorithm problem solving and attempting to better converge with (100) iteration while considering grid parameters. Also, through proposed method, the MINLP problem is turned into an NLP problem with considerable reduction in the computational burden and runtime. But for Achieving low runtime using GAMS software and MINOS solver in future work are recommended.

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