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Design and Analysis of Lagrangian Algorithm for Power Flow System using Renewable Energy Resources

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Abstract

This paper mainly deals with the implementation of an Lagrangian Relaxation (LR) technique through a Supervisory Control and Data Acquisition (SCADA) system. Maintaining Power Station is not an easy task which to achieve its demand such as regulating inputs monitoring energy losses. In this paper we have introduced novel SCADA based decentralized approach to minimize the loss of the system and optimize the total generation cost. Due to the nonlinearities of Electricity demand and scheduling time, the problem is not solvable with the usual optimization techniques. For getting appropriate solution LR technique has been formulated as a nonlinear programming problem with respect to optimal energy constraints. Based on the numerical calculations and graphical representations the renewable energy sources are optimally allocated in individual and hybrid an configuration, which leads to effective production.

***Keywords**: Lagrangian Relaxation (LR), Renewable Energy Sources (RES), SCADA, Transmission, Optimal Power Flow, Energy Management, Distribution Automation*

1. Introduction

The Large increase of distributed energy resources, including distributed generation, storage systems and demand response, especially in distribution networks, makes the management of the available resources a more complex and crucial process. Energy generation requires the advanced techniques for monitoring, control and supervising. SCADA systems are used to manipulate environmental elements at a variety of sites. Data collection functions such as Programmable Logic Controllers (PLC), Remote Terminal Units (RTU) are used in these sites to display variables which include temperature, lighting and entry systems. The manipulate functions of these systems can be used to hold unique environmental factors at these websites, maintaining refrigeration units online, preserving unique heating levels and entry systems. This may be very plenty useful for just-in-time manufacturers by means of and automating generation so that the call for is met precisely, which reduces the total operating cost.

1.1. Literature Review

In past research, Bayrak et al [1] proposed a power management model based on residential solar-hydrogen power plant hence the tested results ensures that the proposed method is suitable hybrid power management system is easy to implement. Hari et al [2] proposes a Ant Line Optimization algorithm whose inspiration from the hunting behaviour of ant lions, six step hunting behaviour is modelled using six easier operations for solution procedure with a variety of difficult constraints. Subramani [3] survived a comparative study on advanced optimization techniques with Lagrangian Relaxation technique. The design and analysis of Lagrangian Decomposition model has been discussed by Subramani et al [4], which ensures that Lagrangian functions provide the optimum solution for the proposed decomposition techniques with respect to penalty factors. Controlled and uncontrolled parameters are identified to solve Lagrangian dual problems which optimizes the main problem. Particularly the Lagrangian multipliers added in the objective function of the Lagrangian problem which is acting as "penalty factors", based on the parameters of the system. On decomposition technique the Lagrangian Multipliers (λ) are used to relax one or more constraints in such a way that main

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problem gets optimal solution. Omar et al [5] the utility of renewable energy resources for scientific developments to shine their contributions to the society and its future prospects.

Generation cost for electricity by renewable technologies are generally assumed to be more than the generation cost through conventional technologies, but Partrige [6] tests the converse of the above statement using learning rate analysis, based on large samples of wind and small hydro projects in India, and projects likely changes in these costs through 2020. Wei Zhu Deng et al [7] presented a photovoltaic-thermoelectric hybrid based power generation system also; a cost and energy utilization analysis has been made by combining photovoltaic, photo-thermal and thermoelectric conversions. Gireesh et al. [8] examines the design and implementation of Renewable Energy Certificate market in India and its effectiveness international best practices based on the objectives. This analysis determines the appropriate price bounds.

Kyeongseok Kim et al [9], proposes a real options analysis framework as a tool to assess renewable energy investment in developing countries. A case study has been conducted involving a hydropower project in Indonesia which is validated and verify the proposed framework. The proposed framework would expected to help host countries and investors assess renewable energy projects with high volatility and risk. Rajib Baran Roy [10] provides the various applications and needs for automations using the SCADA system electricity network. The data of automation is useful for getting a clear picture of the overall status of the system. The application of SCADA has simplified the managing of the electricity network, which is desirable to improve the overall system performance, reliability and stability it is necessary to implement the SCADA system for controlling the whole electricity network.

Yong Li [11], proposed a concept of net load for combined forecasting approach with model self-adjustment for renewable generations and energy loads in smart community. The proposed method can significantly improve the forecasting accuracy. Renaldi et al [12], was modelled a case study as a mixed-integer linear programming problem and implemented with different time grids, i.e. single-uniform, multiple-uniform, and multiple-non-uniform. Abdmoule et al [13], analyzed the applications of optimization techniques in Integration of Distributed Generation using Renewable Energy Sources

1.2. Real Time Network Analysis

From the SCADA system, starts with 'current state' and executes programs sequentially. Network topology is to design a network model based on real-time measurements. This can be done in various ways i.e., private wire line, buried cable, telephone, microwave radios, Wi-Fi, microwave dishes, satellites or other atmospheric means. The state estimator determine 'best' estimate from real-time measurements of the model of the system, and this provides Voltage branch flows, (state variables). Detect and identify discordant measurements called bad data. Filter out smaller errors due to model approximations and measurement inaccuracies. Power flow loads the flow analysis (Voltages, Phase angles, Voltage angles etc).

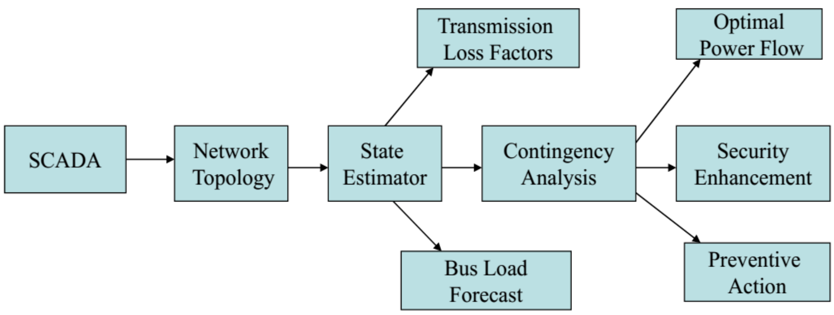

Figure 1. Real-time Network Analysis

A list of contingencies is processed as applicable to current state. Contingency is one of the security analysis applications in power utility. Generally a ranking method will be demonstrated to prioritize transmission planning. Contingency is an event that causes important component to be removed from service (eg: turbine-line, generator, transformer) and Contingency Analysis which impact of a set of contingencies to identify harmful ones.

2. Mathematical Model

Optimization model is designed with respect to flow and cost, existing models are optimizes the flow alone whereas our proposed model optimizes with respect to time, cost and flow.

2.1. Parameters

N − Connected node set;
C_{Si} – Start up cost of unit i at time k;
$P_D(k)$ – System load demand at time k;
$C_{V\,i}$ – Voltage Cost for unit i at time k;
$C_{BIO\,i}$ - Cost for Biomass production in unit i at time k;
$C_{PV\,i}$ – Cost for the production of photovoltaic unit i at time k;
$C_{WIND\,i}$ - Cost for the production of Wind units i at time k;
$C_{F\,i}$ - Fuel cost for thermo - electric unit i;
$F_{k,i}$ − Flow input in unit i at time k;
F_i^{min} − Minimum input flow level;
T – Study time;
V_i − Voltage magnitude of flow i;
V_i^{max}, V_i^{min} − Upper and lower bounds of voltage units;
θ_i − Voltage phase angle of flow i;
$I_{PV\,i}$ - Photovoltaic unit i electric power;
I_{PVi}^{max}, I_{PVi}^{min} – upper and lower bound for Photovoltaic i unit in electric power;
θ_i^{max}, θ_i^{min} – Upper and lower bounds of voltage phase angle for flow i;
e_i − per unit transmit power of flow i;
$I_{BIO\,i}$ - Biomass i unit electric power;
$I_{BIO\,i}^{max}$, $I_{BIO\,i}^{min}$ - Upper and lower bound for Biomass unit i;
$I_{WIND\,i}$ - Wind i unit electric power;
$I_{WIND\,i}^{max}$, $I_{WIND\,i}^{min}$ - Upper and lower bound for Wind unit i;
$I_{F\,i}$ - Fuel cost for thermo – electric unit i;
I_{Vi}^{max}, I_{Vi}^{min} - Upper and lower bound for Voltage unit i
$P_i(k)$ – Power output of unit i at time k;
P_i^{max}, P_i^{min} – Upper and lower bounds of power flow in transmission line i at time k;
$R_i(k)$ – Allocated reserve power of generation i at time k;
$I_i(k)$ – Decision state of flow i at time k.

2.2. Optimization Model Formulation

$$Min \sum_{i=1}^{N}\sum_{k=1}^{T}\left[C_{Si}I_i(k) + C_{vi}I_i(k) + C_{pvi}I_i(k) + C_{BIOi}I_i(k) + C_{WINDi}I_i(k) + C_{Fi}I_i(k)\right] \quad (1)$$

$$Max \sum_{i=1}^{N}\sum_{K=1}^{T} F_{k,i} \quad (2)$$

$$Min \sum_{i=1}^{N}\sum_{k=1}^{T}[\; C_{Si} + C_{vi} + C_{pvi} + C_{BIO\,i} + C_{WIND\,i} + C_{F\,i} \;] \quad (3)$$

Subject to:

$$\sum_{i=1}^{N} I_{Fi} + \sum_{i=1}^{N} I_{BIOi} + \sum_{i=1}^{N} I_{WINDi} + \sum_{i=1}^{N} I_{PVi} + \sum_{i=1}^{N} I_{Vi} \geq \sum_{i=1}^{N} I_{DEMAND} \quad (4)$$

$$\sum_{k=1}^{T} F_{k,i} + \sum_{i=1}^{N} V_i \geq \sum_{k=1}^{T}\sum_{i=1}^{N} P_i^{\min} \qquad \forall\ i = 1,2,3,\ldots,N \quad (5)$$

$$\sum_{k=1}^{T}\sum_{i=1}^{N} F_{k,i} \geq F_i^{\min} \qquad \forall i = 1,2,\ldots,N \quad (6)$$

$R_i(k) + P_i(k) \leq P_i^{max}(k)$, $\forall$ i =1,2,3,…,N (7)

$V_i^{min} \leq V_i \leq V_i^{max}$, $\forall$ i =1,2,3,…,N (8)

$\theta_i^{min} \leq \theta_i \leq \theta_i^{max}$, $\forall$ i =1,2,3,…,N (9)

$I_{V\,i}^{min} \leq I_{V\,i} \leq I_{V\,i}^{max}$, $\forall$ i =1,2,3,…,N (10)

$I_{PV\,i}^{min} \leq I_{PV\,i} \leq I_{PV\,i}^{max}$, $\forall$ i =1,2,3,…,N (11)

$P_i^{min}(k) \leq P_i(k) \leq P_i^{max}(k)$, $\forall$ i =1,2,3,…,N (12)

$0 \leq R_i(k) \leq P_i^{max}(k) - P_i^{min}(k)$ $\forall$ i =1,2,3,…,N (13)

$$\sum_{k=1}^{T}\sum_{i=1}^{N} P_i I_i(k) \leq P_D(k) \qquad \forall\ i = 1,2,3,\ldots,N \quad (14)$$

$I_{WIND\,i}^{min} \leq I_{WIND\,i} \leq I_{WIND\,i}^{max}$, $\forall$ i =1,2,3,…,N (15)

$I_{BIO\,i}^{min} \leq I_{BIO\,i} \leq I_{BIO\,i}^{max}$, $\forall$ i =1,2,3,…,N (16)

$V_i - e_i\theta_i \geq 0$, $I_{F\,i} \geq 0$, $\forall$ i =1,2,3,…,N (17)

3. Lagrangian Decomposition Model

From the above model it is clear that flow is the only constraint which are directly related to the objective, hence treating that as a complicating constraint, the Lagrangian decomposition is formulated by using dual variable (Lagrangian Multiplier λ),

$$L[U,\lambda] = Min\left[Max\left[\sum_{i=1}^{N}\sum_{k=1}^{T} F_{k,i} + \sum_{i=1}^{N}\sum_{k=1}^{T} \lambda_i\left(F_{k,i} - F_i^{min}\right)\right]\right] \quad (18)$$

Subject to:

$P_i^{min}(k) \leq P_i(k) \leq P_i^{max}(k)$ $\forall$ i =1,2,3,…,N (19)

$0 \leq R_i(k) \leq P_i^{max}(k) - P_i^{min}(k)$ $\forall$ i =1,2,3,…,N (20)

$V_i^{min} \leq V_i \leq V_i^{max}$, $\forall$ i =1,2,3,…,N (21)

$\theta_i^{min} \leq \theta_i \leq \theta_i^{max}$, $\forall$ i =1,2,3,…,N (22)

$I_{V\,i}^{min} \leq I_{V\,i} \leq I_{V\,i}^{max}$, $\forall$ i =1,2,3,…,N (23)

$I_{PV\,i}^{min} \leq I_{PV\,i} \leq I_{PV\,i}^{max}$, $\forall$ i =1,2,3,…,N (24)

$I_{WIND\,i}^{min} \leq I_{WIND\,i} \leq I_{WIND\,i}^{max}$, $\forall$ i =1,2,3,…,N (25)

$I_{BIO\,i}^{min} \leq I_{BIO\,i} \leq I_{BIO\,i}^{max}$, $\forall$ i =1,2,3,…,N (26)

$V_i - e_i\theta_i \geq 0$ and $\lambda_i \geq 0$, $\forall$ i =1,2,3,…,N (27)

LR replaces the original problem into associated Lagrangian problem using Lagrangian multiplier (λ). This is obtained by relaxing one or more complicating constraints of the proposed model, and adding these complicating constraints to the objective function associated with Lagrangian multiplier. The difference between the bounds is known as 'gap'. If the gap reaches to zero or sufficiently small due to the model approximation, the analyst may stop the iteration.

4. Numerical Calculations and Graphical Representations

The Generation Scheduling gives the cycles for generation of units. The Lagrangian Decomposition models are solved by MATLAB 2010a. The data sets used for the LD models are real time data sets. From the Table 1, the maximum power generation is obtained in 11 set of connected nodes with the Total Operating Cost (TOC) Rs. 24500 is obtained where the planning schedule period one cycle. After eleven set of nodes the TOC becomes constant. Figure 2 ensures that the TOC reduced uniformly till it becomes constant. The level of significance occurred at the end of 7 hrs.

Table 1. Total Operating Cost (in `) for 1000 units

Set of Connected Nodes (N)	Study Time (N_t) hrs	Voltage (I_v) volts	Photovoltaic (I_{pv}) w atts	Wind (I_{wind}) units	Biomass (I_{bio})	Fuel `	Total Operating Cost `
1	20	700	800	1000	900	3000	58300
2	19	688	808	1045	945	3100	55700
3	17.50	676	856	1120	950	3150	51800
4	17	611	942	1122	953	3196	59200
5	15.25	590	954	1140	960	4010	45950
6	13	576	978	1178	979	4020	40100
7	11	542	1057	1199	993	4200	34900
8	8.45	528	1090	1233	1019	4218	28270
9	7.15	508	1136	1270	1035	4230	24890
10	7	487	1167	1297	1083	4320	24500
11	7	473	1189	1307	1090	4335	24500

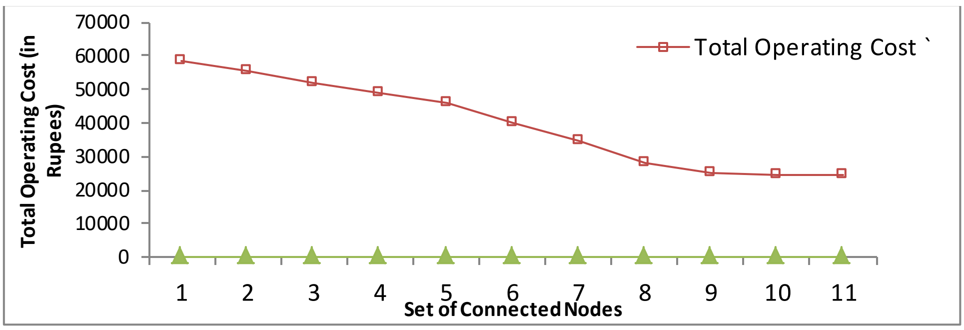

Figure 2. Total Operating Cost (in`) for 1000 units

On the other hand while using LR Technique the minimum generation cost of Rs. 21083 obtained in eleven set of connected nodes cost Rs. 53792 is obtained where the planning schedule period one cycle per day. Figure 3 reveals that the generation cost reduced compared to the original cost while using LR technique

Table 2. Optimum Generating Cost in LR Technique

Set of Connected Nodes (N)	Study Time (N_t)hrs	Voltage (I_v) volts	Photovoltaic (I_{pv}) watts	Wind (I_{wind}) units	Biomass (I_{bio})	Generated λ	Total Operating Cost `
1	20	700	800	1000	900	0.8006	53792
2	19	688	808	1045	945	0.9106	50985
3	17.50	676	856	1120	950	0.8021	50367
4	17	611	942	1122	953	0.9891	47866
5	15.25	590	954	1140	960	0.8854	43700
6	13	576	978	1178	979	0.7037	40060
7	11	542	1057	1199	993	0.3372	33745
8	8.45	528	1090	1233	1019	0.6821	26307
9	7.15	508	1136	1270	1035	0.1879	23651
10	7	487	1167	1297	1083	0.3372	21770
11	7	473	1189	1307	1090	0.7102	21083

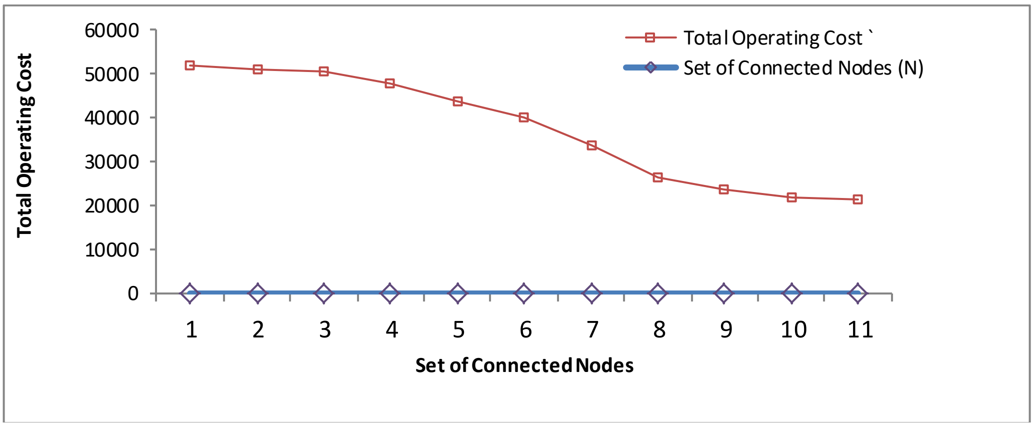

Figure 3. TOC vs Set of connected Nodes using LR Technique

A comparative study has been made based on total operating cost. From Figure 4 it is clear that always Lagrangian Relaxation Technique will give less than or equal to the solutions of original model. Hence Lagrangian technique is useful for obtaining lower bound for any optimization problem.

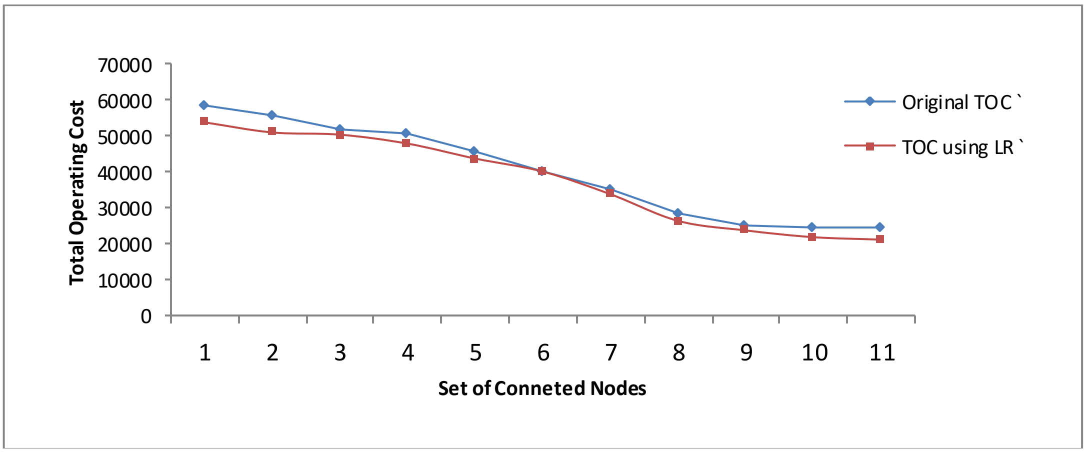

Figure 4. TOC: Original vs LR

Table 3. Maximum Wind Penetration for wind units

Period	Wind Power Penetration (in PSO Method)	Wind Power Penetration (in LR Method)
January	309.5142	309.9757
February	315.2331	317.5009
March	274.4152	275.3818
April	233.7942	233.8268
May	531.9416	533.3464
June	1316.5230	1316.5690
July	1800.7143	1835.8270
August	1787.8232	1848.6251
September	1489.5130	1505.4217
October	1072.5495	1081.6248
November	173.3142	176.4862
December	327.6143	328.4626

From the Table 3, that the maximum wind power penetration (wind energy shared on the grid) 1848.6251/ MU is obtained by using active power output from the wind farms. Therefore, the maximum load utilized is in the month of August in the year 2015-2016 by the wind power plants. A comparative study has been made with other soft computing technique, Particle Swarm Optimization. The tested result shows that the Lagrangian Relaxation produces the appropriate solution for real time experiment with respect to time, cost and other atmospheric factors.

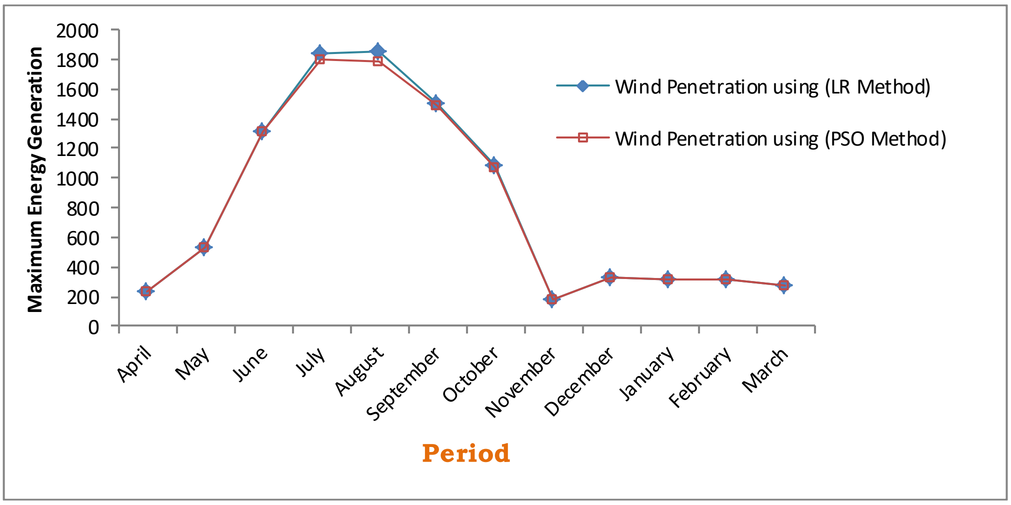

Figure 5. Maximum load utility period for wind units

Figure 5 show that the maximum power is utilized in the month of August for thermal wind units. Generation Scheduling provides the maximum wind power penetration for wind units over a time interval that satisfies the demand and operating conditions of the power system.

5. Conclusion

This paper presents an optimal energy control efficient strategy for power management system with respect to optimal energy constraints. A Non-Linear Programming Problem has been formulated for minimizing loss of the system over controlled variables. Due to the nonlinearities of electricity demand and planning horizon the problem is not solvable in easy manner. A novel SCADA based decentralized approach has been introduced to optimize the generation cost and flow. The capacity of the transmission lines are optimally allocated based on the availability of the energy resources. Based on the Numerical calculations and graphical representations, the proposed model leads to effective production by minimizing the loss of the system.

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