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Power System Operation Cost Optimal Location

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Abstract Voltage control and system stability rely heavily on reactive power. In electric power systems, various Volt/VAR techniques are used to keep the voltage profile within a defined acceptable range, providing reliability, stability, and economic benefits. Reactive power has traditionally been generated by large-scale synchronous generators or distributed capacitor banks to provide proper transmission and distribution level system management; however, reactive power can also be used to reduce total system operation costs. The operating cost of a power system, often referred to as fuel cost, represents the expenses incurred in purchasing and using fuel to generate electricity in power plants. These costs can vary depending on the type of fuel used (e.g., coal, natural gas, oil, or renewable sources) and the efficiency of the power generation process. This reduction in operation cost will be accomplished by adjusting nodal reactive power, which will have an impact on network power flow. The main purpose of this paper is to determine the optimum bus in pwer ssyem where the opartion cost mostly reduced by adjustable reactive power. The proposed model's applicability and performance are validated using IEEE 30-bus.

Keywords Reactive Power, Operation Cost

1. Introduction

THE importance of power system opration cost is increasing with growing demand for electrical power by many domestic and industrial utilities in the power system network depending on reactive power management. It is required to generate energy in a more efficient, reliable, and cost-effective way. Effective way of delivering electrical energy utilizes technologies such as flexible AC transmission system (FACTS) and static voltage compensation (SVC) to maintain voltage stability, high power factor, and less transmission losses. Reactive power plays crucial role in the power system network [1].

Reactive power is considered as the essential part of the ancillary service that supports the power transmission from its generation site to the customer. Services may include load regulation, spinning reserve, non-spinning reserve, replacement reserve, and voltage support. Reactive power has a profound effect on real energy transfers and on security of power system as it affects the voltage profile throughout the system, makes the power system more reliable, and guarantees power flow in the system. It is not desirable to transport reactive power over the network [1]. As a consequence, ancillary services (e.g., regulation and operating reserves, power frequency control, power balance, voltage control, and restoration of supply), which are generally procured through short-term competitive market mechanisms, are gaining more and more importance in the process of supporting renewables integration in the grid. Reactive power cost is divided into reactive power capacity cost and reactive electricity quantity cost [2]. Maximum profit of reactive power can be obtained when the marginal revenue equals marginal cost [3].

A. System or Device Description

The previous studies on reactive power mostly focused on its management and pricing. The study in [4] suggests a model to evaluate economical price of reactive power. The reactive power is made as a supporter for an electrical network where its pricing gives the support for system in both economical and operational sides. This was illustrated in [5]. Reactive power pricing has been proposed to incorporate the operation cost of generator for the reactive power production cost as ancillary service. New full Newton methodology to represent the reactive power generation limits in the power flow problem is proposed by using a set of sigmoid switches that incorporates new equations into the problem formulation [6]. A simple method to optimize the power delivery of photovoltaic system to utility grid is suggested in [7]. Three kinds of models are presented to solve the optimal reactive power flow in wind generation

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integrated system. The models are carried out in a modified IEEE 14-bus system. According to simulation results, the features of models are analyzed and compared [8]. The overview of the possibilities, limits, pros and cons of the reactive power control of wind turbines are explained in [9]. The authors in [10] present a methodology to remunerate the ancillary services of generation reserve and reactive power support as a function of the benefit provided by generators to the power system. The comparison between the provision of reactive power support ancillary service in distribution networks and conventional equipment such as capacitor banks and distribution generation units based on renewable resources is illustrated in [11]. A method of equivalent reactive power compensation is improved to measure the difference among reactive power resource value in [12]. The problem of pricing reactive ancillary services is addressed and formulated as a joint cost allocation problem in [13]. The investigation of the extent of forecasting electricity prices of ancillary services over a 24-hour horizon is illustrated in [14]. The description of the developed methods of definition of a payment for voltage and reactive power control by power stations is discussed in [15]. The control of active and reactive power between inverter and utility grid using the d-q theory has been proposed in [16]. Reactive power shortage and the associated voltage violations due to the failures of reactive power sources are considered in [17].

A detailed model is presented for the incorporation of the distributed generation (DG) units' reactive power limits in the power flow formulation in [18]. A control strategy for reactive power compensation is presented in [19]. Reactive power shortage and the associated voltage violations due to the failures of reactive power sources are considered in [20] where new reliability indices are proposed to represent the effect of reactive power shortage on system reliability. A novel correction method is proposed in [21] to achieve rapid reactive power control on synchronous generators. In [22], particle swarm optimization and its variants are applied to calculate the optimal real and reactive power to manage power congestion in the system. A method to calculate the optimum real and reactive power that maximizes social benefit and minimizes the operation cost of power system is presented in [23]. A mathematical model for reactive power pricing structure based on various cost components is developed in [24]. The design of a competitive market for reactive power ancillary services is discussed in [25] using a compromise programming approach based on a modified optimal power-flow model. A reactive power economical dispatching method is proposed using power flow simulator in [26]. A model to find optimum real and reactive in embedded wind generation and battery energy storage system is proposed in [27]. A framework for reactive power management to protect voltage stability at maximum marginal while keeping active and reactive power at economical dispatch is presented in [28]. A novel solution for optimal reactive power dispatch problem is handled by a new mathematical approach for voltage magnitudes in [29]. In [30], reactive power cost is analyzed using theory of marginal cost at various loads. It is discussed in this study that power factor penalty of load and addition of reactive power cost to real power cost are two methods to recover reactive power cost. Moreover, it is discussed that reactive power generation leads to decrease the real power generation. As a result, an opportunity cost of reactive power is introduced to recover real power production. Moreover, capacitive reactive power cost and its allocation are evaluated to get minimum cost using linear programming techniques. Reactive power could be provided by renewable sources to distribution grids which would reduce the transmission system operation cost, improve system security, and reduce ancillary services cost [31]. Reactive power control and distribution system face many challenges specifically in the presence of wind and photovoltaic sources as these sources operate at maximum tracking power point which is affected by weather condition.

The interfacing and interconnection of DG units in microgrid to general grid is offered usually by power electronic devices to get operation control in flexible mode. However, there are quality problems caused by these devices, and reactive power compensation represents one of them in supporting load and voltage. Reactive power/ voltage and active power/ frequency are main ways to control power in microgrid besides droop control [32]. The reactive power droop control was presented in [33] where voltage reduction is used by integration of the reactive power. In this control method, microgrids operate as active power filter to get harmonic compensation of reactive power. All these control techniques are applied in microgrid to achieve reactive power compensation.

B. Model Outline and Formulation of Optimum Reactive Power Calculation In Power System

The objective of this paper is to determine the optimum reactive power of all buses in the system that results in the lowest cost system operation. In other words, the nodal reactive powers are adjusted in a way that the cost of real power generation in the system is minimized. Synchronous generator’s capability curves are provided by manufacturers in standard condition. They are used for loading the synchronous generators in different operating loads without exceeding the designed limits. Generally, nominal capacity of a synchronous machine can be indicated by MVA in a specific voltage and power factor (usually 85-90% of lead) in which the synchronous machine is able to work continuously without abnormal temperature increment. Real output power of the synchronous machine depends on turbine ability and nominal MVA machine limits. A synchronous generator can produce real power only if there is enough reactive power to support it. Otherwise, the generator is no longer able to generate real power due to policy of security system [30]. Generators have maximum and minimum of real and reactive power capabilities. The maximum reactive power capability is associated with operating with lagging power factor. The minimum reactive power capability corresponds to the maximum reactive power the generator may absorb when operating with leading power factor. In some electrical generators such as DFIG, the operation at maximum reactive power limit leads the electric system to operate near the steady state stability limit, which is undesirable [30].

2. Theory of Proposed Idea

The proposed model's goal is to find the optimal bus that guarantee the lowest total system operation cost when In other words, the nodal reactive powers are adjusted so that the system's cost of real power generation is minimized. The objective function is defined as the sum of individual unit costs, each presented as a second order function of its real power generation. Pi represents the unit i's real power generation, and a, b, and c are the constant cost coefficients. This goal is constrained by operational constraints (2).

$$\min \sum_{i}(a_i P_i^2 + b_i P_i + c_i) \quad (1)$$

$$P_i^{\min} \le P_i \le P_i^{\max} \qquad \forall i \in \mathrm{G} \quad (2)$$

$$Q_i^{\min} \le Q_i \le Q_i^{\max} \qquad \forall i \in \mathrm{G} \quad (3)$$

Table 1. Operation cost vs reactive power for standred Case 30 IEEE

Load Bus NO	Basic Reactive Power (MVAR)	Optimum Reactive Power (MVAR)	OBJECTIVE FUNCTION
3	1.2	-0.02	576.79
4	1.6	-5.28	576.65
5	0	-0.98	576.89
6	0	-12.67	576.73
7	10.9	-0.077	576.89
8	**30**	**-1.53**	**573.84**
9	0	28.02	576.64
10	2	-0.41	576.20
11	0	-16.2	576.66
12	7.5	2.62	576.89
14	1.6	0.06	576.87
15	2.5	0.32	576.82
16	1.8	0.06	576.77
17	5.8	0.05	576.50
18	0.9	0.11	576.72
19	3.4	0.04	576.64
20	0.7	0.16	576.63
21	11.2	0.04	576.68
24	6.7	0.07	576.80
25	0	-0.75	576.86
26	0	0.04	576.81
28	0	0	574.40
29	0	0.20	576.79
30	0	0.33	576.88

3. Simulation or Experimental Results

The proposed model is formulated in MATPOWER and applied to IEEE 30-bus standard test system as shown in Fig. 2.

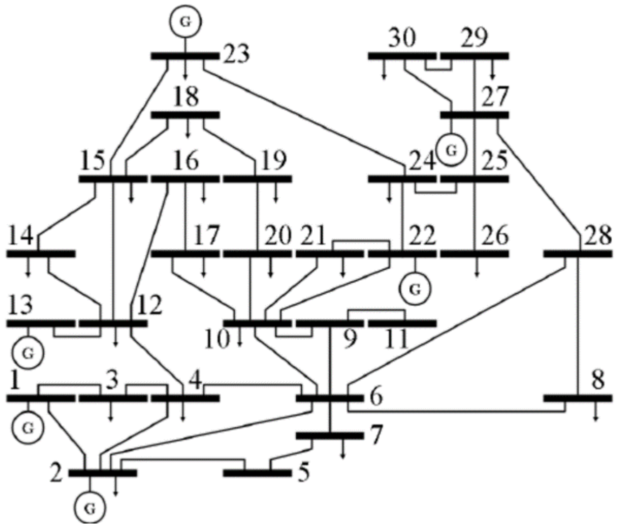

Figure 1. Case 30 IEEE Standred system

The basic operation cost os $567.79.Then the reactive power is changed in variable manner at each bus individually, and the lowest operation cost with corresponding reactive power is calculated and listed in Table 1.

Table 2. Optimum bus

Case Number	Optimal Bus	Basic Objective Function $	Minimum Objective Function $
CASE IEEE 30	8	576.79	573.84

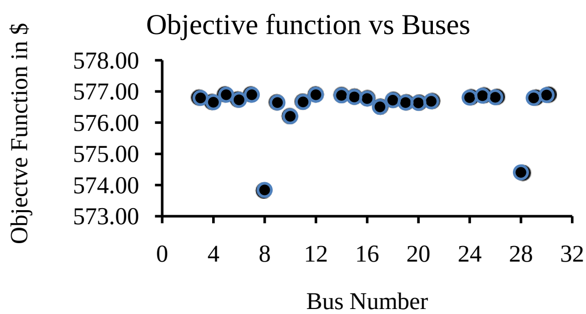

Figure 2. Objective Function vs Buses

4. Conclusions

Minimizing the power system operation cost objection function is critical for economic power system operation by reducing system losses where reactive power is an important factor in reducing system losses. The primary goal of this paper was to determine the optimum Bus in a power system in order to minimize the total system operation cost. To that end, a nodal reactive power variable was introduced into the optimal power flow problem, and the optimal buses with the greatest impact on lowering system operation costs were identified. The proposed model was tested on IEEE 30 bus standard systems and the bus number 8 was determined as optimal operation cost location.

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