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Linear Optimization for Power System Resource Plan with Transmission Limitations and Large Renewable Power Sources

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***Abstract*— The planning and real-time operation of an electric power system, including high-voltage direct-current transmission and variable generation resources, is a complex optimization problem with several key constraints emblematic of the western bulk electric system. First, the optimization must incorporate and properly integrate the engineering requirements and limitations of the entire generation fleet, while simultaneously and continuously balancing the system electric load. Second, the western electrical grid is typically known for its sporadic load centers that are physically separated from most power generation resources, requiring transmission capacity that is both limited and necessary to serve the electric load dozens or hundreds of miles away. Third, the optimization problem is made more difficult with the introduction of variable generation resources, including wind and solar energy. This paper presents an optimization model and its application for analyzing a power system resource plan with basic power system requirements including generation and transmission constraints. The results show that the greatest opportunities to optimization planning occurs during medium load levels, and in cases of extreme high and low load levels opportunities for optimization are very limited.**

Keywords*— *Power system resource plan; transmission limitations; renewable power sources; linear program; sensitivity analysis

I. INTRODUCTION

The traditional Bulk Electric System (BES) is a complex network of power generators, transmission resources, and power consumers. The BES must be kept in continuous equilibrium as mandated by the North-American Electric Reliability Corporation (NERC), a nonprofit international regulatory authority, whose mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid and subject to oversight by the Federal Energy Regulatory Commission (FERC) [1]. Due to the complexity of system conditions, power supply & demand, and weather events, maintaining a balanced BES can be a challenging task. Also, the electric power generated in the system at any moment must be consumed somewhere essentially at the same instant due to the fact that electricity travels at about 1/1000th the speed of light [2]. Historically, the planning and designing of electric power systems has largely been an ad-hoc process, where additional transmission and generations resources are added as needed. The inherent ad-hoc nature of BES growth and development can lead to built-in weakness in the system, which result in non-optimal resource utilization. Due to the nature of the vast physical separation between electrical load centers and the generation resources that serve them, the western transmission grid has added limitations. That is, some of the largest power generating resources (including the Palo Verde Nuclear Generation Station in Arizona and the wind farms in eastern New Mexico) are hundreds of miles from the load centers they serve and as such are limited by the transmission resources available. For the resource optimization of electrical power systems, therefore, several critical variables must be considered, including the transmission & generation resources, their operating cost (both traditional and renewable generation resources), and the forecasted demand level. The system dynamics of the typical western transmission constrained BES are further complicated with the recent and planned introduction of substantial renewable power sources that are inherently variable, unreliable, and very difficult to predict (note that wind energy is a greater concern as solar energy is more predictable and less variable relative to wind power). Typical of a western BES, the BES in New Mexico is an electrical grid with pockets of load centers spread across large geographical distances, which are served by generation resources that must contend with limited transmission availability and sporadic mix of traditional generation resources such as coal, gas, and nuclear generated electrical power plants. The Public Service Company of New Mexico (otherwise known as PNM) is the largest electrical utility in New Mexico and the optimization of the PNM system is made more difficult due to the growing penetration (as a percentage of all available generation resources) of various renewable power sources that are inherently variable and (mostly) uncontrollable.

In this short paper, we present a simple yet practical optimization approach, which employs a linear program, to minimize the cost of producing power to serve the load demands of the PNM BES. The PNM BES encompasses the entire power generating fleet (traditional and renewable generation resources) and some transmission capacity of the PNM system. The system model will then be used in developing an unit schedule for specific load level in three load scenarios, all of which will provide power to the three load centers that make up the PNM BES: Northern NM, Southwestern NM, and Southeastern NM. The proposed optimization model will take into consideration several key system limitations that influence the optimization of the BES, such as: a predicted load value driven largely by temperature and time of year; a generating unit's specific unit cost, which is related to and can measure the unit's efficiency relative to the cost of fuel; as well as specific monetary drivers of renewable energy sources derived from contractual agreements and obligations. Therefore, this analysis will be performed in order to:

- develop a power system resource plan that will specify for PNM BES operators how to optimize the entire PNM generation fleet to meet anticipated hourly power demands of the three load centers during three scenarios: peak load, medium load, and low load
- find and specify the anticipated output level for the PNM generation fleet
- compare through sensitivity analysis the variables of the optimization plan that have the greatest flexibility of the resource plan.

The following analysis should also provide insights that are not discernable simply by intuitive practice or brute force trial-and-error approaches. The anticipated knowledge gained should provide decision makers, both front line employees and management at PNM, with the awareness to make short- and long-term resource plans that provide the most cost effective strategies in resource utilization that will ensure the PNM ratepayers the greatest value as well as transparency in the decision making process for all stakeholders, including the New Mexico Public Regulation Commission who oversees PNM [3].

II. DATA

In conducting the supportive research, PNM publishes substantial information and documentation to the NM PRC as a regulated utility, and some of the data sourced for this research was obtained through published public information from the PNM website [4] as well as the NM PRC website [3]. Information obtained from both of these sources are current given that PNM is mandated by state government regulators to submit, every three years, an Integrated Resource Plan (IRP), which is a public planning process that serves a roadmap for PNM on current and future plans for the PNM BES.

A. Generation Resources

This research considers various generation resources including coal power, gas power, wind generation, solar generation, and nuclear generation. Figure 1 shows the system map of PNM generation fleet and transmission. Note that two of the plants located on the map, PEGS and Pyramid, while located within the PNM BES, are not part of the PNM generating fleet. These two generation resources are owned and operated by a distinct and separate utility (an electrical power co-op called Tri-State Generation and Transmission Association) and as such are not included in this objective function. Also, the map in Fig. 1 does not include the Palo Verde Nuclear Plant located in Arizona, of which PNM is a minority stakeholder of the plant's three nuclear reactors.

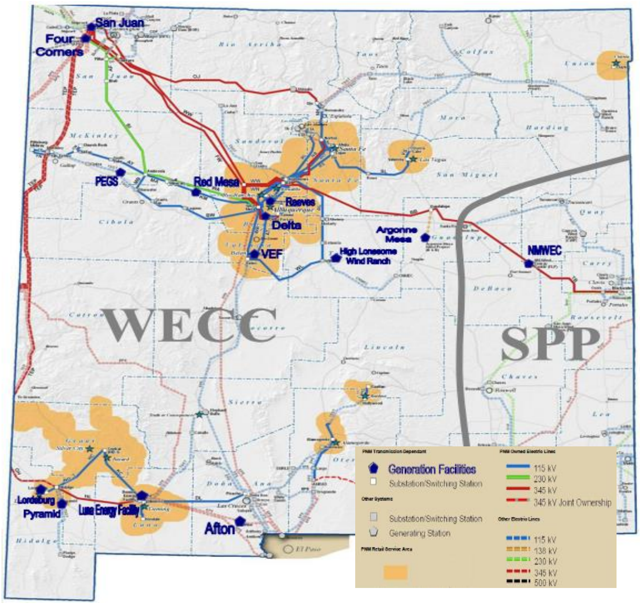

Fig. 1. PNM GENERATION FLEET AND TRANSMISSION SYSTEM (SOURCE: [5])

Coal Power Sources Starting in the northwest corner of the state both Four Corners and San Juan are coal-fired power plants. Note that, of the original five units at Four Corners Generating Station (FCGS), only two remain in operation: Unit 4 and Unit 5. Both units have a gross output capacity of 750 MW (Megawatts), and since PNM owns 13% of the plant output, PNM will have about 94 MWs from each unit (once auxiliary power is subtracted the net output of each unit is about 720 MWs). The Four Corners region of New Mexico also includes San Juan Generating Station (SJGS), which has two of the original four units remaining in operation: Unit 1 and Unit 4 (Unit 2 and 3 were retired just two years ago). The ownership of Unit 1 is split 50/50 between PNM and Tucson Electric Power (TEP). Hence, PNM is entitled to half of the 370 MW gross unit output. Once 30 MWs of auxiliary power is subtracted (auxiliary power is the power consumed by the generator in order to operate and thus subtracts from the gross output) PNM receives 170 MWs for power from Unit 1. PNM owns a majority share of Unit 4 at SJGS, which has a gross output rating of 544 MW; after auxiliaries this unit provides PNM with 385 MWs of generation. In total, PNM has the capacity of up to 743 MWs of coal power generation.

Gas Power Resources The PNM BES has an ownership, part ownership, or PPAs (a Power Purchase Agreement is a contract between PNM and an independent power producer for the right to purchase the generation output of a power plant) with seven gas-fired power plants, most of which are purposely located within or near the Bernalillo load center – the largest load pocket of the PNM BES. In the ABQ metro there are two: Reeves Generating Station and Delta Generating Station (also known as Rio Bravo). Reeves Generating Station is a three-unit, 154 MW gross output gas-fired power plant built in the 1950s and owned and operated by PNM. After auxiliaries Unit 1 and 2 have a net output of 40 MWs each, while Unit 3 has a net output of 60 MWs. Rio Bravo is gas-fired power plant originally designed as an oil-fired power plant. It is a simple cycle combustion turbine (CT) with a net output of 140 MWs and is fully owned and operated by PNM. Further south in Valencia County is Valencia Energy Facility (VEF), another simple cycle combustion turbine (CT) gas-fired power plant with a net output of 150 MWs which has operated since 2008 under a PPA with PNM. In 2015 a “peaker” power plant (so called “peakers” are small gas-fired turbine power plants that can be quickly started and used to generate power for peak load demand) named La Luz was installed in Valencia County (west of VEF and south of the Belen Airport), a 40 MW net output power plant owned and operated by PNM. Moving to the southwest part of New Mexico there is Lordsburg Generating Station (LGS), Luna Energy Facility (LEF), and Afton Generating Station (AGS). LGS is a two-unit generation station with two 40 MW “peaker” gas turbines owned and operating by PNM since 2002. East of LGS in Deming is LEF, a gas-fired two unit combined cycle plant (meaning in addition to the turbine CT there is a heat capture system that uses excess steam energy, called a steam turbine or ST, to increase output and operating efficiency) with a total net output of 600 MW – this plant setup is in industry parlance referred to as a 2x1 plant (two CTs with a single ST). PNM does not directly operate or own the plant but does manage the plant and owns one third of the plant output along two other entities who each own one third: TEP and Phelps Dodge Energy Services, a subsidiary of Phelps Dodge Corp. After auxiliaries PNM is entitled to up to 188 MWs of the plant output. East of LEF and south of Las Cruces is AGS, a gas-fired 1x1 power plant (meaning a single CT and ST) with a gross output of up to 240 MWs and a net of 220 MWs. PNM owns and runs the plant and while seemingly located randomly in the middle of nowhere is in fact constructed directly above a major natural gas line, allowing for easy fuel access for the power plant.

Wind Generation Resources PNM has three distinct PPAs that supply it with the output of three wind facilities in New Mexico. Located east of Albuquerque in Cibola County is Red Mesa Energy Center, a 100 MW wind generation plant own by NextEra Energy Resources made up of 64 1.6 MW GE xle turbines. Southeast of Albuquerque in Torrance County is a 100 MW wind generation plant made up of 40 2.5-megawatt Clipper turbines also owned by NextEra Energy called High Lonesome Mesa Wind Energy Center. Further east in De Baca and Quay counties is New Mexico Wind Energy Center (NMWEC), a wind farm consisting of 136 1.5 MW GE turbines capable of producing 200 MWs also owned by NextEra Energy. There are several other wind farms within the PNM BES but they are contractually obligated to supply energy to utilities outside of the PNM system so they do not directly factor into the optimization scheduling of the PNM generation fleet and are transported out of the PNM BES. Although they utilize some of the transmission capacity of the PNM BES, they are excluded from this research since 1) they use transmission leaving the PNM BES, which does not impact import transmission capacity and 2) the modeling required to accurately describe the export transmission impact on any PNM optimization is beyond the scope of this research.

Solar Generation Resources The PNM BES has in the last few years seen an explosion of solar renewable energy, both in residential and commercial (utility-scale) applications. Residential solar is what is referred to as “behind the meter” energy and is created by residential installations of solar panels, typically on the roof of a household. The “behind the meter” utility parlance is important because this energy is not directly measured by the utility, and is only measured as so called negative load, where it reduces the actual measured load value (since it reduces the load demand by supplying some amount of energy); while not directly measurable, total estimated residential solar currently sits around 130 MWs and is expected to see very strong growth in the years to come. Commercial, utility-scale solar has also seen strong growth, with various solar farms spread throughout the PNM BES as far south as Deming and as far north as Santa Fe. Currently, the total utility-scale solar output capacity is about 200 MWs.

Nuclear Generation Resources PNM is a part owner of the three units at Palo Verde Generating Station that produce up to 3.3 GW (Gigawatts) of power, making Palo Verde the largest power plant in the United States by net generation capacity. PNM has a 10.2% ownership of Palo Verde, which is operated by Arizona Public Service Company (APS), giving PNM up to 405 MWs of power capacity (135 MWs from each of the three units). When Palo Verde is at full output power, it is the single largest hazard and risk liability for a reserve sharing group that PNM is a member of. More on that topic will be covered in the Reliability Resources section. Additionally, since Palo Verde is located in Arizona and outside the PNM BES, it requires significant transmission resources to wheel the energy back into New Mexico.

B. Transmission Resources

The PNM transmission system can largely be classified into one of two types: internal transmission and external transmission resources – which is relative to the PNM Balance Authority (or PNM BA). NERC defines a BA as the "responsible entity that integrates resource plans ahead of time, maintains demand and resource balance within a Balancing Authority Area, and supports Interconnection frequency in real time." [6] What this means pertinent to this research is that transmission resources (and generation resources for that matter) external to what is the PNM BA need extra monitoring beyond internal resources due to the crossing of BA boundaries. Note that Figure 2 also shows a comprehensive map of the PNM transmission resources. Additionally, if certain generation resources are within the PNM BA, this means that they "sink" directly into the BA and do not require explicit use of transmission systems. Of course, all generation resources require some transmission facilities to transport and deliver their power generation (with corresponding transmission limits), but for the sake of general resource optimization it is not typically considered, and it is assumed the generation resources within the BA have full transmission capacity to accept up to the maximum power plant output without limitations. The generation resources that are considered internal of the PNM BA (and thus no transmission constraints) are SJGS (coal plant), all of the three wind farms previously mentioned, all solar generation (including residential and utility), Reeves (gas), Rio Bravo (gas), La Luz (gas), and VEF (gas). This means that there are varying transmission constraints for the remaining generation resources: FCGS (coal), LGS (gas), LEF (gas), AGS (gas), and Palo Verde (nuclear). The transmission constraints for the individual plants are summarized in Table 1, and are split by the two geographical load centers of the PNM BA, i.e., Northern New Mexico (NNM) and Southern New Mexico (SNM). Southern New Mexico is also split into Southwest New Mexico (SWNM) and Southeast New Mexico (SENM). Note that, while SJGS has no transmission restrictions to serve load in NNM, up to (but not more than) 75 MWs of transmission is available to serve load in SNM (see Table 1 for more information).

Table 1: Transmission Constraints for External Generation Resources

Generation Resource	Transmission
FCGS (coal)	188 MWs of available transmission, all to serve NNM
SJGS (coal)	The majority of generation is synced to NNM (SJGS is internal to the PNM BA), but up to 50 MWs of transmission is available to serve SNM (either SWNM and/or SENM) and up to 25 MWs of transmission is available to serve SENM
LGS (gas)	50 MWs of available transmission to serve NNM, 30 MWs to serve SWNM, 20 MWs to serve SENM
LEF (gas)	178 MWs of available transmission, 120 MWs to serve NNM, 30 MWs to serve SWNM, and 20 MWs to serve SENM
AGS (gas)	220 MWs of available transmission, 175 MWs to serve NNM, 25 MWs to serve SENM, and 20 MWs to serve SWNM
Palo Verde (nuclear)	409 MWs of available transmission, all to serve NNM

C. Reliability Resources

The operating reserve can be classified into two types: regulating reserve and contingency reserves. Regulating reserves is excess online capacity to meet the natural variation of load demands which will invariably differ from expected load forecasts. PNM has implemented a standard 13% reserve margin target in its generation capacity planning [7]. Contingency reserve is further split into two categories: spinning reserve and non-spinning reserve [8]; these reserve amounts are dictated by NERC in order to increase the reliability of the BES. Spinning reserve is simply additional online generation capacity beyond what is needed to serve demand, a NERC reliability requirement in order to respond to and recover from an event or a disturbance on the BES (both within and outside the PNM BES) including the loss of a generation resource. Non-spinning reserve is a NERC reliability requirement that requires extra generating capacity that is not currently online but available to be online within ten minutes. The required amount of contingency reserves is based on 3% of the BA's load and 3% of the BA's online generation. Within the contingency reserve calculation, at least half of the contingency reserves must be carried by generators that are online, unloaded, and able to respond to immediate changes to interconnected system frequency (so-called spinning reserve). During the peak load, PNM's spin and non-spin quota is approximately 125 MW, plus enough additional contingency reserves to recover from a failure of PNM's single largest hazard. Since PNM is a member of the Southwest Reserve Sharing Group (SRSG), it reduces the amount of contingency required to either 232 MWs (to cover SRGS Unit 4) or 70 MWs (to cover AGS). For the sake of this research required contingency reserve requirement will simply be added generation capacity beyond the peak load value, so using a peak load of 1800 MWs, we add 125 MWs for spinning reserve plus 232 MWs for non-spinning reserve, for a total of 2157 MWs.

III. Problem Formulation and Assumptions

For convenience, all notations used in the model formulation are summarized as below:

Sets:

R	Set of all service regions in New Mexico (NM) indexed by i
R_N	Set of all service regions in Northern New Mexico indexed by i
R_{SE}	Set of all service regions in Southeastern New Mexico indexed by i
R_{SW}	Set of all service regions in Southwestern New Mexico indexed by i

Input Parameters:

C_i	Cost of serving the megawatts of electrical load in region i
D_N	# of megawatts (MW) of loads from all service regions in Northern NM
D_{SE}	# of megawatts (MW) of loads from all service regions in Southeastern NM
D_{SW}	# of megawatts (MW) of loads from all service regions in Southwestern NM
L_i	Lower limit (in MW) on generation capacity in region i
U_i	Upper limit (in MW) on generation capacity in region i

Decision Variables:

X_i	# of megawatts (MW) covering the service region i

The objective function (1) minimize the total operating cost over a dispatch period (assumed to be one hour) and it will be used to determine the generation level for all units. Note that due to operating constraints in their normal operation, two of the gas plants (Afton and Rio Bravo) and Four Corners coal plant have minimum output levels where the plants cannot operate and produce energy below a certain threshold. Also, it is difficult to model dynamic variables such as renewable energy, so the approach used in this research is to assume a baseline output level of wind and solar resources based on the capacity factors measured in New Mexico by the Department of Energy. Additionally, since renewable energy is not curtailable due to economic concerns, the generation constraint for both wind and solar energy were implemented as equality constraints, where all wind and solar energy generated must be incorporated into the resource plan, standard practice for normal system operations of the PNM BES. While there are instances when wind energy would be curtailed for reliability concerns in order to balance generation to load (a NERC requirement and basic function of all power system operators), such modeling is beyond the scope of this study.

$$\text{Minimize } \sum_{i\in R} C_i X_i \qquad (1)$$

This objective function is subject to two types of constraints as follows:

$$\sum_{i\in R_N} X_i \geq D_N \qquad (2)$$

$$\sum_{i\in R_{SE}} X_i \geq D_{SE} \qquad (3)$$

$$\sum_{i\in R_{SW}} X_i \geq D_{SW} \qquad (4)$$

The transmission constraints (2) through (4) ensures that each service region in Northern, Southeastern, and Southwestern New Mexico will receive respectively sufficient power to meet its peak load. In our case, the peak load values are 2037 MWs for Northern NM, 70 MWs for Southeastern NM, and 50 MWs for Southwestern NM.

$$L_i \leq X_i \leq U_i \ , \quad \forall i \in R$$

Constraint (5) ensures that each service region will meet its lower and upper limit on generation capacity requirements. Before proceeding to the results of the case study, some important assumptions factored into the proposed optimization model should be noted. First, the heat rate of a combustion power plant (a standardized measure of the efficiency of a power plant) has a linear relationship with power output of a plant; in other words the higher the plant output the higher the efficiency of the plant on a per MW basis. The "H Rate" variable is the greatest efficiency possible of the power plant and will be the values used in the model, but in actual operation the plant's heat rate will vary and degrade from these values since the plant rarely will be a full output. Second, the two gas-fired power plants that are combined cycle have inherent limitations that require a certain period of time before the plant can be in put in combined cycle, which means that depending on the ambient temperature and the recency of operation, the plant requires anywhere from two to eight hours to be available for full output. These timing limitations were not considered in this research. Third, due to contractual agreements established in the PPAs, generally all wind resources are determined as "must-take", meaning any power generation of the wind farms must not be curtailed. There are some exceptions to this mandate including in conditions where system reliability is a concern, but for the purposes of this research it is assumed all wind generation is must take (for solar energy there is currently no ability to curtail it). Fourth, since renewable energy is not dispatchable (the output is controlled by the weather), there is an amount of inherent variability in the output of both solar and wind generation sources. For this research, the U.S. Department of Energy's average capacity factor for New Mexico wind and solar generation in 2017 (the most recent year of provided data) is applied [9]: the capacity factor for solar is 27% and wind is 37.2%. For this general research case it will be assumed that all renewable energy sources will have their corresponding output capacity applied to their respective plant output, including all wind farms, residential solar, and commercial solar.

IV. Results and Discussion

The proposed optimization model was run for three different scenarios and the corresponding results are discussed in the following.

Scenario #1 (Peak Load) The optimization model for the peak load is fairly straight forward since most of the generation resources of the PNM BES must be utilized in order to meet such high load demand. The total unit cost to serve 2157 MWs of load for one hour was $51,531.01. Since the load value is substantial, the entire generation fleet is online and in operation, with the cheapest resources base loaded, also known as at full output (coal, nuclear, and the largest gas plants). In such a peak scenario, even the "peaker" $100 resources are in use, including all of Lordsburg 1, 21 MWs of Lordsburg 2, and all of La Luz. This means that less than 19 MWs of excess generation exist in this scenario. While this is not a realistic scenario (PNM has never had such a high peak value), it shows the robust ability of the PNM BES to respond to future load growth as well as the ability to respond to contingency events, even with the transmission restrictions and generation resources stranded in the southern part of the state that must be "wheeled" back up to serve Northern New Mexico load.

Scenario #2 (Medium Load) A medium load scenario of 1250 MWs is in some ways the most interesting of the modeling scenarios since the transmission and generation restrictions come more into play than simply having almost all resources online as shown in the Scenario #1. The total unit cost to serve the medium load for one hour was $18,695.67. In this case, 35 MWs of Luna generation is used, while Afton is at minimum output and Rio Bravo is at minimum load. Also, SJGS is nearly base loaded, while FCGS is half load and all Palo Verde is used. In fact, this resource plan selected by the optimization modeling is identical to resource plan used in early November/late October. The optimization information of this load level epitomizes the drastic operating cost difference between serving mild load amounts and having to serve an additional 900 MWs; the cost increases by around a factor of 3, from roughly $18k to over $50k.

Scenario #3 (Low Load) The low load scenario involves modeling a load value of 950 MWs, which is considered to be the minimum load level experienced by the PNM BES. The total unit cost to serve the medium load for one hour was $15,388.30. In this minimum load scenario most of the online units are at their minimum load levels: Afton, Rio Bravo, and all coal units are at their lowest possible load levels. Just over 60% of Palo Verde generation is needed with the rest having to be sold off (since nuclear units are always base loaded if they are online they must be at maximum output and cannot be curtailed or used for regulation). This resource plan is emblematic of the middle of the day load levels during the shoulder months when temperatures are pleasant and mild, with very little inductive motor loads and no need for either heating or cooling. The low load optimization reveals that, while the reduction in generation resources is fairly significant from 1250 MWs to 950 MWs (a drop of 300 MWs), the cost is fairly flat and does not drop much relative to the reduction in generation output. This reveals that the system does not have much cost flexibility on the lower end of the output spectrum, and that due to the nature of the system operating parameters the PNM BES is not particularly suited for cost optimization on the lower end of the output capacity.

V. Sensitivity Analysis

The sensitivity analysis for this study includes investigating the effects of changing the output level of the generation resources & the load amount and it follows a dichotomy of two patterns.

For the case of Scenario #1, since most available generation capacity is used in the resource plan, it is not surprising that there is not very much flexibility (roughly 20 MWs) in reducing the output of individual power plants without affecting the optimal resource plan. Although there is a potential energy capacity to serve the southern load centers, but this is in application limited by the current transmission capacities and are unlikely to change in the near future.

For the case of the other two scenarios with lower generation output levels, there is generally large flexibility in moving power plant output without impacting the optimal resource plan, but fairly limited in flexibility in reducing the generation output levels without affecting the optimal plan. The sensitivity analysis for Scenario #2 stands in stark contrast to the analysis of the first scenario. As expected, with many generation resources unloaded and not at full output, there is a lot of flexibility in increasing or decreasing plant output without impacting the optimal resource plan. The largest allowable decrease in unit cost corresponds to the most expensive generation resources, which means that at the medium load level significantly reducing the unit cost of the highest cost generation units will not affect the optimization plan. The sensitivity analysis for Scenario #3 reveals considerable flexibility in increasing either the output level of the generation resources or the load amount. This insight makes sense since at such low load levels the cheapest generation resources afford the resource plan significant allowable increase without changing the resource plan; similarly, for the same reason the resource plan has considerable allowable decreases in load level without changing the resource plan. In short, at the lower end of the load levels the resource plan of the PNM generation fleet is not a very efficient use of the available generation resources, so an increase or decrease of 100+ MWs of load will not change the optimization plan. At this level of load, any increase in cost to any of the generation fleet except nuclear would have no impact to the resource plan. This means that the PNM system (and likely most if not all power systems) are not optimized to serve load demands on the lower level of their anticipated load levels. The three most expensive generation resources will have massive reductions in cost and not affect the resource plan since they are not used at all in this load scenario.

VI. Conclusion and Future Research

This study presented a way to use a rather common mathematical programming technique to gain insight into analyzing a power system resource plan with transmission limitations and large renewable power sources. The proposed optimization model of the PNM BES reveals that at both of extremes of anticipated load levels the ability to optimize the power system are very limited, although for different reasons. In the peak load scenario, the ability to optimize the power system is small simply because the load demand is so high that in order to meet the demand almost all of the entire generation resources must be used. Therefore, optimization concerns take a backseat to meeting the energy demand. Conversely, in the low load scenario, the ability to optimize the system is also small because at such low load demands there is such an excess of generation resources that even the cheapest source of energy must be curtailed or sold off (potentially at a loss) in order to balance generation with load. The PNM BES is not optimized to produce such low levels of generation output. By far the greatest opportunity to optimize the system occurs during periods of moderate load amounts, as modeled in the Scenario #2. The analysis reveals that the resource optimization plan is very sensitive to price fluctuations of the generation resources in the middle of the unit cost range. Marginal improvements to those generation resources will likely have an impact on the resource plan. Hence, PNM management and decision makers should be aware that changes to the cost of gas and coal (the fuel used by resources in the moderate range of unit cost) could have significant changes in the use of those energy resources – if cost optimization is the main driver in managing the resource plan for the PNM BES.

The proposed mathematical program is not a perfect model of the actual PNM BES. Future research should focus on the following: (1) One of the major limitations is that dynamic variables were not included. dynamic variables could be used to better model the engineering limitations of the PNM generation fleet, where heat rates vary depending on the load level of the power plant (so the overall efficiency of the power plant improves as the unit output reaches the maximum power output). While the general unit costs will not change significantly due to heat rate variability, it would provide a more accurate model of real-world operations; furthermore, dynamic variables would also more accurately reflect the natural variability of renewable resources, which were simply modeled as static resources at reduced output using their New Mexico capacity factor; (2) The PNM BES can be impacted by transmission resources internal and external of the PNM BA. The three load centers of the PNM BA (NNM, SWNM, and SENM) have some transmission capacity not modeled in this analysis that if included would enhance the modelling accuracy of the optimization analysis; and (3) This linear optimization did not factor in any way potential market conditions. Depending on the supply and demand of energy in the Western Transmission grid, it could impact the resource optimization particularly of the medium resource plan since more of less generation resources would be used; if market conditions were strong additional generation might be used to increase the profitability of the resource plan, and conversely, less generation resources would be used if the market price of power was less than the cost of generation from the PNM fleet. These optimization decisions occur frequently in real-world applications, so if future optimization research could factor market conditions in some what it could provide additional insight for resource planning for all system operators.

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