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A Multi-Institutional Approach to Delivering Shared Curricula for Developing a Next-Generation Energy Workforce

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ABSTRACT In this paper, we consider collaborative power systems education through the FEEDER consortium. To increase students' access to power engineering educational content, the consortium of seven universities was formed. A framework is presented to characterize different collaborative education activities among the universities. Three of these approaches of collaborative educational activities are presented and discussed. These include 1) cross-institutional blended courses (''MS-MD''); 2) cross-institutional distance courses (''SS-MD''); and 3) single-site special experiential courses and concentrated on-site programs available to students across consortium institutions (''MS-SD''). This paper presents the advantages and disadvantages of each approach.

INDEX TERMS Engineering education, power engineering education, multi-institutional collaboration.

I. INTRODUCTION

In 2013, the US Department of Energy launched the Grid Engineering for Accelerated Renewable Energy Deployment (GEARED) as a part of its SunShot program. One of the primary goals was to create ''training consortia that focus on quickly bringing their findings into training and educational initiatives'' [1]. The program was motivated in part by a number of studies indicating there was a shortage of power systems engineers [2]. These studies also predicted that impending retirements in the industry were going to make the shortage worse, with as many as 62% of the electricity and natural gas utilities workforce eligible for retirement. One study indicated utilities would need to hire more than 7000 new power engineers to replace retiring engineers. Furthermore, the replacement power systems engineers needed education on new technologies related to increased integration of renewables, more distributed power generation, and new grid technologies. Not only was there a shortage of graduating power engineers, but there was a projected shortage in the US of faculty to prepare this power workforce of the future, with 40% eligible to retire in the coming years [3].

The Foundations for Engineering Education for Distributed Energy Resources [FEEDER] consortium of universities was created in response to, and with the support of, the US Department of Energy SunShot GEARED program. The consortium initially consisted of seven universities,[1]

[1]The initial group of institutions consisted of Auburn University, Florida State University, University of Arkansas, University of Central Florida, University of Florida, University of Kentucky, and University of South Carolina. The consortium was later expanded to include University of California San Diego, University of Hawaii, University of Pittsburgh, University of Texas at Dallas, and San Diego State University.

as well as partner industries and national labs. Although the FEEDER consortium has a scope that includes research, university education, and industry training related to power systems, in this paper we focus specifically on the university education activities of FEEDER. Specifically, we will introduce three collaborative education models we have utilized and the opportunities and challenges associated with each. The education models and their associated activities are focused around the following premises:

- There is a heavy projected demand for power engineers to replace retiring engineers, and the demand exceeds the ability of any one or two institutions to meet the demand.
- Education for the modern power engineering workforce needs to include modern topics such as renewable energy generation, integrated distributed power technologies, advanced grid controls and management, communication and security, as well as non-technical content on power system economics, policy, environmental impacts, and social impacts.
- Few institutions have the teaching resources (e.g., faculty specialties and faculty capacity) available to teach the whole range of these topics on a regular basis.

A basic principle of the FEEDER consortium is that *the faculty instructional resources and expertise across the FEEDER consortium institutions is greater than the resources and expertise within any single institution.* By tapping into subject expertise and teaching resources across multiple institutions, each institution is able to increase the number, type, and frequency of course offerings available to students. This allows the consortium to prepare more students for the modern power engineering workforce than the set of institutions could do acting separately.

Similar to FEEDER although not specific to power engineering, the Australian ''Hubs and Spokes'' project was motivated by a need to address an Australian engineering skills shortage [4]. In the Hubs and Spokes project, the goal was to allow students geographically distributed at ''spoke'' universities to benefit from specialized courses delivered from discipline ''hub'' universities with ''specialist centres of excellence''. In that program, all courses are taught in a *blended format*, where the students received some content by distance learning, supplemented by live local instructors, and received course credit towards a degree from their local institutions [5]. The FEEDER consortium is similar in that it was also created in response to an engineering skill shortage, but differs in structure. As opposed to the uni-directional Hubs and Spokes model, the FEEDER institutions depend on a more balanced and collaborative approach, where expertise is distributed across and teaching is sourced from multiple universities. The FEEDER approach considers not only blended delivery modes, but also a pure distance mode and live ''summer institutes'' where students receive concentrated live instruction and educational experiences.

In the following sections, we will provide an overview of the FEEDER consortium educational approaches, more deeply consider each approach, and finally compare the approaches and outline future directions.

II. OVERVIEW OF FEEDER EDUCATIONAL APPROACHES

In the early stages of the FEEDER consortium, a survey of 11 industry partners was done in order to seek input on 36 potential course topics. These industry partners were primarily from the electric utility industry, but also included power equipment manufacturers and other related industries. The industry partners were to consider each potential course topic and rate both its importance to power students in general and also to students to be employed directly in their company (each rated on a five point scale, with ''5'' as ''critically important – must have within a curriculum''). The industry partners were also asked to indicate a level of coverage expected (rated as either ''Deep'' or ''Shallow''). Thirteen topics received an average of 4.0 or above, indicating they were either ''very important'' or ''critically important'' for power systems students (Table 1). Thirty-four of the 36 topics rated an average of 3.0 or above, indicating important.

TABLE 1. Top results from curriculum survey from 11 industry partners. The "Importance in General" rating was on a 5-point scale, with "5" representing "critically important – must have within a curriculum".

Topic	Rating on "Importance in General"
Electric Power System Fundamentals (phasors, one-line diagrams, 3-phase systems, load flow basics, component modeling)	4.75
Power Quality	4.50
Power System Reliability	4.44
Power System Fault Analysis	4.38
Power System Economics	4.38
Power System Relaying and Protection	4.25
Power Generation (overview of generation methods, including coal, gas, nuclear, hydro, wind, solar, etc.)	4.25
Renewable Power Generation (focus on solar, wind, geothermal, hydro)	4.25
Power System Transients	4.13
Power Distribution Systems	4.13
Solar Power Generation using Photovoltaics (devices, large and small systems, siting and design, system integration and control, economics and policy)	4.13
Power System Stability and Control	4.00
Grid Integration of Renewable and Distributed Generation	4.00

The survey results reveal three important desires from the utility/industry perspective. First, as expected, utilities and industries want to hire graduates who have a solid understanding of fundamental concepts as well as a variety of analysis/design tools in power systems. Indeed, many of the topics in Table 1 are "classical", and our FEEDER institutions have been teaching these courses. Therefore, it makes sense that the institutions continue their individual course offerings in a traditional way, while looking for creative and synergistic ways of collaborating to enhance course availability and offerings and frequency.

Second, our utility/industry partners recognize the need of understanding a diversified power generation portfolio as well as integration of renewable and distributed generation. Recent research has shown that renewable energy integration calls for a paradigm shift of power systems operation from centralized decision making to decentralized yet supervised decision making. To prepare for this shift, our graduates need to learn advances in not only renewable resources but also control, optimization, data analytics, cyber-physical systems security, as well as relevant topics in economics and public policy. While the survey did not provide a roadmap of how to best cover all these topics, academic faculty members need to take the lead, integrate the state of the art research into classrooms, develop new courses, and train our graduates for this transformation.

Third, the topics in Table 1 range from broad and fundamental ("Power System Fundamentals" and "Power Generation" basics) to much more specialized ("Power System Relaying and Protection" or "Power System Economics"). No single university within the FEEDER network offered all top 13 topics prior to the consortium, and none of the universities had teaching resources to offer all topics to their students on a frequent and regular basis.

In addition to the initial industry survey, many of the FEEDER institutions used additional industry input mechanisms. These included informal interactions with local utilities and industries, and more formal interactions through local industry advisory boards (departmental or center boards). In some cases, this additional industry input was used to help refine the course content within the broader topic, as well as bring in relevant real-world examples from industry.

The industry feedback of curriculum topics was used to identify top priorities for course development. These items were circulated and shared between FEEDER institutions and faculty, and faculty were asked to partner with other faculty members and develop shared courses based on their own expertise and interests and industry input. Thus, this selection of initial courses to develop was decentralized and loosely coordinated, not centrally directed. This is consistent with the approach of FEEDER to leverage the expertise and interests of a broad multi-institution faculty base to achieve the objectives of the FEEDER curriculum.

Since each university within the consortium had expertise in different, focused areas of the newly, identified curriculum, the FEEDER consortium decided to try different modes of delivery. In order to deliver a wide array of power engineering related education content to students from the different FEEDER institutions, the consortium decided upon three different approaches of cross-institutional educational activities.

- The first was a *cross-institutional blended course*, where content was developed across multiple instructors across multiple institutions, and then delivered by distance and supplemented or integrated with live instruction by a local faculty member.
- The second approach was a *cross-institutional distance course*, where content was developed by a faculty at one or more institutions, but delivered exclusively through distance learning to students at other institutions.
- The third approach was a *cross-institutional educational experience*, where students from across multiple institutions were brought together in one location for a short-term (approximately one week), live, intensive educational experience. Since FEEDER has held these programs during the summer, they were referred to as "summer institutes." The program included classroom work and visits to industrial, national lab, or research demonstration sites related to the focus of the summer institute.

Which mode of delivery used was decided upon by the location where the instruction was delivered and the instruction source for the topics (Fig. 1). *Single-institution instruction source* (SS) was where a faculty member or a team of faculty members at a single institution were fully responsible for the course content and presentation (whether distance or live). *Multi-institution instruction source* (MS) was when faculty members at multiple institutions collaboratively contributed to the course, through the course content development and/or the delivery (whether distance or live). *Single-institution delivery* (SD) refers to a course where all students for a given course were at a single location or affiliated with a single university. *Multi-institution delivery* (MD) refers to a course where students at multiple universities were collectively taking a course.

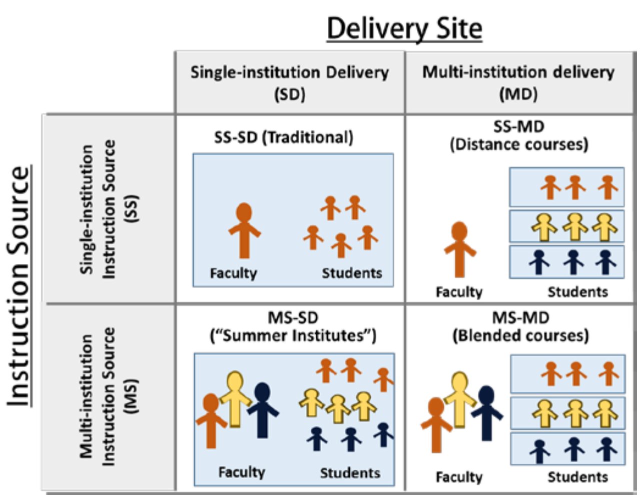

FIGURE 1. Cross-institutional approaches to developing and delivering course content.

Figure 1 shows different combinations of the Instruction Source and Delivery Site. Traditional university education is typically SS-SD, taught either by a single instructor or a co-located team of instructors, and delivered to students attending exclusively the instructor's institution. Note that the delivery could be live or by distance, but all students were located (physically or virtually) at a single institution. In order to address the broad educational goals of the FEEDER consortium and its industry partners, the three educational activities briefly described above were developed corresponding to the remaining quadrants in Fig. 1. Each quadrant has its own benefits and challenges, and these are discussed in further detail below.

III. BLENDED DELIVERY FOR MULTI-INSTITUTION INSTRUCTION SOURCE, MULTI-INSTITUTION DELIVERY (MS-MD)

Multi-institution Instruction Source, Multi-institution Delivery (MS-MD) is when there are multiple institutions contributing to the content creation and multiple institutions are aiding in the delivery of that content. MS-MD is considered the highest form of collaboration and delivery since there are multiple institutions involved at each stage. While there are several different forms a MS-MD course can have, in each variant we consider, the content is developed by instructors over several institutions, and students have a local instructor at their own institution that is responsible for local coordination, including registration, grading, and portions of content delivery.

MS-MD Example: A course is co-taught by instructors at University A and University B, with teaching of content alternating between the two instructors over the semester. Students at University A will receive the content from University B via online methods, and vice versa. Students at University A will have their course material coordinated by their local instructor at University A, with their local instructor responsible for assigning grades for the course, and same for University B.

Because of the distance between the FEEDER institutions, the MS-MD courses include some distance teaching (on-line or video) methods. In an MS-MD course, the local instructor at an institution (such as the instructor at University B for the students at University B) typically has some live interaction with the students, such as periodic live lectures or problem solving sessions. In this form, the class fits what is often referred to as a "blended delivery mode", where students at each institution have a blend of online content with live content from the local instructor.

There are several variations of collaborative course development and delivery. Blackmore et al. indicate five models of collaboration, ranging from collaborative joint development and collaborative joint delivery of material, to more one-directional development or delivery, or even separate class development and delivery but using pre-prepared course modules [6]. Among the courses taught thus far in FEEDER, the courses have spanned four of these five variations.

The following are advantages of a MS-MD blended course.

- *Administrative Simplicity:* A big benefit of the MS-MD blended course is its simpler administrative implementation, especially when compared to SS-MD (discussed below). Since the MS-MD course assumes each institution offering the course has a local instructor, that local instructor becomes the responsible instructor for course scheduling, registration, and grading. From an administrative perspective, a MS-MD blended course at an institution does not appear different, administratively, than any other course taught by a local instructor.
- *Local Instructor Contact:* In the MS-MD Blended courses, there is a local instructor available to lead class discussions and help students work problems, and address issues with the class that may occur. Although these things can be done at a distance with a distance instructor, some student-instructor interactions are better done live face-to-face [7], [8].
- *Expanded Student Course Offerings*: A MS-MD blended course can bring together expertise of multiple faculty members to create courses that might not be developed and offered at an institution if a faculty member at an institution was working alone or simply did not have that area of expertise within their unit. This is especially true for courses in newly developing areas, where there is a lack of instructional texts and basic content in the field is still evolving. Furthermore, developing a new course in an emerging area may require more time than a single instructor working alone is able to devote, so collaboration on the course development and delivery means that students can now have courses available that otherwise might not have been developed or delivered at their institution if faculty were working alone. For one of the courses, an overview of Renewable Energy, content elements were developed by five different faculty and one industry representative. This brought together expertise on various topics that was beyond the knowledge of any single involved faculty member.
- *Savings on Development Time per Faculty* (vs. single instructor course development): The multiple faculty who share development of the course material means that each individual faculty member is not solely responsible for the content at his/her own institution. This would represent a savings of faculty development effort in general. However, determining the savings is somewhat complicated by extra effort expended by each instructor in preparing content for distance learning. Still, when multiple faculty come together with a common interest, multiple ideas and resources can come together for a unique course experience that results in a meaningful and significant learning experience [9].
- *Potential for Faculty Cross-learning:* Each collaborating instructor brings an area of expertise to the course material. Other instructors collaborating on the course may now come away from the course with knowledge gained from the other instructors and the students as the students digest the course material and give feedback.
- *Secondary Collaboration Benefits of Faculty*: Faculty who begin collaborating on a course become familiar

with each other, and are more likely to consider collaboration on research proposals or activities. Anecdotal evidence among institutions in the FEEDER consortium indicate research collaboration among faculty has increased after faculty members collaborated on course development and delivery. The benefits of networking opportunities and cross-learning of the faculty should not be underestimated.

While the advantages of the MS-MD blended course delivery are many, there are still some challenges associated with it including, but not limited to:

- *Potential coordination challenges between multiple instructors for determining course calendar, content, and delivery style:* Having multiple instructors is both a benefit and a challenge. It is a benefit because it brings together different expertise from the different instructors. It is a challenge because now multiple instructors must agree on content, teaching style, grading, and other course details. Wang et al outline many of the challenges with cross-institutional collaboration of faculty, including challenges with differing institutional cultures, teaching pedagogies, preferred course structures, and even personal communication styles [10]. In the FEEDER experience so far, there were no instructor conflicts noted, but it is certainly a possibility in collaborative work. Also, course coordination across institutions can be a challenge due to different calendars across institutions. For example, one institution may start or end a semester earlier than another, or may have a different holiday or semester break schedule.
- *No gain in instructor teaching resources*: Since a MS-MD blended course requires the involvement of a local instructor, it does not release an instructor for other teaching. Thus, the local students still would see the same number of courses available to them based on their local faculty teaching resources, even though the cross-institution collaboration may give these students a wider variety of such courses.
- *Differences in student preparation or expectations across institutions:* Students from different institutions may have different preparation based on prior courses at their institution or the degree they are pursuing. This challenge became evident with one of the early multi-institution blended courses: at one institution, the registered students were mostly upper level undergraduate students, whereas at the other institution, the registered students were mostly graduate students. The instructors at the two institutions presented material most appropriate for their own local students, which in some cases was a mismatch for the preparation of or expectation of the different students.

The MS-MD blended mode is arguably the most appropriate for new multi-disciplinary courses, as it allows multiple faculty members with complementary backgrounds (and often at different institutions) to contribute to a single course. FEEDER has developed MS-MD courses on topics such as Global Energy Issues, Introduction to Renewable Energy, Distributed Control and Optimization for Smart Grid, Communications and Networking for Smart Grid, Integration of Distributed Generation, and Integration of Photovoltaics.

Between Spring 2015 and Fall 2016, six FEEDER institutions have delivered 13 sections of MS-MD blended courses. (It should be noted that two of these sections were local versions of the MS-MD course, with the same blended format and online content as experienced at other sites but delivered to students at the source site.) In order to evaluate the progress and effectiveness of the MS-MD blended delivery method, student mid-semester and end of course evaluations were analyzed from nine sections of MS-MD course offerings using constant comparative analysis [11].

Overall, students had a mixed impression of the blended courses, especially as it related to the online content across the various MS-MD course offerings. When online content was viewable outside of class time, a majority of the students liked the online content, saw it as a convenience, and found it helpful for later reviewing material prior to assessments. These comments also emphasized the benefit of having the online content complement the in-class content (but not repeat it). Typical comments included:

- *"The mix of online and in class is helpful for learning since I can watch and re-watch the lectures at times conducive for learning, and class time helps clarify anything I didn't quite grasp from the videos"*.
- *"The videos are very informative. The in-class stuff enhances what we learn from the videos for an optimal learning experience.*

A majority of the students found the online materials convenient and helpful because *"you can go back and review any information that maybe you didn't understand*" and *"allow me to study when I have the available time."* Some video content in some classes was also rated highly: *"The online component of the class is excellent. The videos are extremely helpful and go at a fair pace."* Student comments pointed out preferred practices, such as when lectures "*very clearly state what will be learned*" and include review questions for helping students study for exams.

Some students complained when videos were required to be watched in the classroom (instead of on the student's own time), and when video content was later reviewed too much or repeated in a subsequent class. Whether required to view in the classroom or at home, some students clearly did not like the online content, finding it *"boring"* and difficult to stay engaged. Example comments were:

- *"I like the class structure, except for the video lectures. I find that they are too hard to pay attention to and drag on."*
- *"The video lectures are a bit tedious. Otherwise the instructors are perfect."*
- *"I do wish there was more lecture and less online video. Nevertheless, [this] is the best class I have taken [here]."*

Students were varied in their response to the number of instructors delivering the content. About half of the students indicated they liked receiving the content from various instructors and the other half found it difficult. Typical negative comments were *"It's hard having two different styles of teaching in the same class.", "The lecture doesn't seem to have any consistency. It feels like each week is a completely different topic",* and *"I dislike the connection of this course with the [distance university]"*.

Students across both local sites and distance sites spoke more highly of their local instructor rather than the distance one, with comments such as "*My favorite part of the course is when we were lectured by [local instructor].",* and *"I get more out of the 5 minutes [local instructor] speaks than hour spent watching the video."*

It is interesting to note that in some classes, each participating instructor received praise from their local students, but were not seen as equivalently effective at the distance institution. From discussions with students, it appears that for at least one pairing of courses, a contributing factor was a difference in student level and student preparation between institutions – at one institution the students were primarily graduate, and the other institution the students were primarily upper level undergraduates. This points out that a local instructor is better able to tailor content to the level of the local students, which may have been a misfit to the students at the distance university. This illustrates one of the challenges of multi-institutional course delivery: adjusting content to the level and preparation of students at multiple institutions.

The reviews indicate that MS-MD course structure can be effective for learning, but the variation in the student reviews indicate that such courses can be of varying levels of effectiveness. Further analysis is needed to determine different success factors across the different classes, such as factors of structure, length, and availability of the recorded content, how students were assessed on the recorded content, and how the content was integrated with the local live instruction and the course.

IV. DISTANCE DELIVERY FOR SINGLE-INSTITUTION INSTRUCTION SOURCE, MULTI-INSTITUTION DELIVERY (SS-MD)

As noted in the prior section, a MS-MD blended course required local instructors at each institution, and so did not release any teacher resources among the institutions. This meant that the number, range, and frequency of courses available to a student were still limited by the availability of local instructor resources. However, this can be overcome through the use of single-institution instruction source, multi-institution distance delivery (SS-MD). In this case, an instructor at one institution teaches a distance course to students in multiple other institutions.

SS-MD Example: An instructor at University A teaches a course on Power Quality by distance learning. Students at Universities B, C, and D take the course from the instructor at University A. The instructor at University A is fully responsible for the course and the grading. At the Universities B, C, and D, there is no local instructor, only a local contact person to manage course listing, the local credit and grades registering, and sometimes proctor quizzes and exams, etc. for the local students.

The advantage of SS-MD distance courses is clear – Students from multiple universities potentially have access to more classes. Even if only one student at University B is interested in a particular offered course, he or she can take it, as long as there is a sufficient number of students across all the FEEDER institutions in order to justify the University A's faculty member's time. Universities with only a few power-engineering related faculty resources would now be able to offer their students a full range of power-engineering related courses.

However, the SS-MD distance courses also pose numerous challenges. The largest of these challenges is administrative. If the instructor at University A is teaching students from University B without substantive involvement of a faculty from University B, then to which institution does the student pay tuition? Will the course from University A count towards a degree at University B? What if University A does not have enough students to offer the course fully at the institution? What are the impacts regarding regional or engineering accreditations?

Because of these administrative difficulties, the FEEDER institutions spent considerable effort in developing a cross-institution course sharing agreement outlining the handling of cross-institution distance courses. The first such courses will be taught in Spring 2017, so no assessment data is available on these yet. However, since these will be operating as a traditional distance course (although across institutions), it is expected that the student experience will be similar to other distance education courses. Thus, the course delivery mode itself will not be novel. What we will focus on in the remainder of this section will instead be the structure of the cross-institution agreement.

The agreement was developed by six of the original seven FEEDER institutions plus the University of Pittsburgh. The agreement has been signed at the provost level of each of the institutions, and involved consultation with units across the different campuses, including registrar offices, assessment offices, finance offices, etc. In the discussion below, we use the term "host institution" to refer to the institution where the SS-MD distance course originates. We use the term "local institution" to refer to the institution where a student is enrolled in a degree program. The local institution must be one of the participating FEEDER universities, and the participating student must be enrolled as a junior, senior, or graduate student. The agreement, shown in operation in Fig. 2, has the following general characteristics:

1. The student's local institution reviews a list of courses to be shared by other FEEDER institutions. The local institution then creates a specially designated course ("local course") for each shared course it chooses to offer. The student then registers for this course at

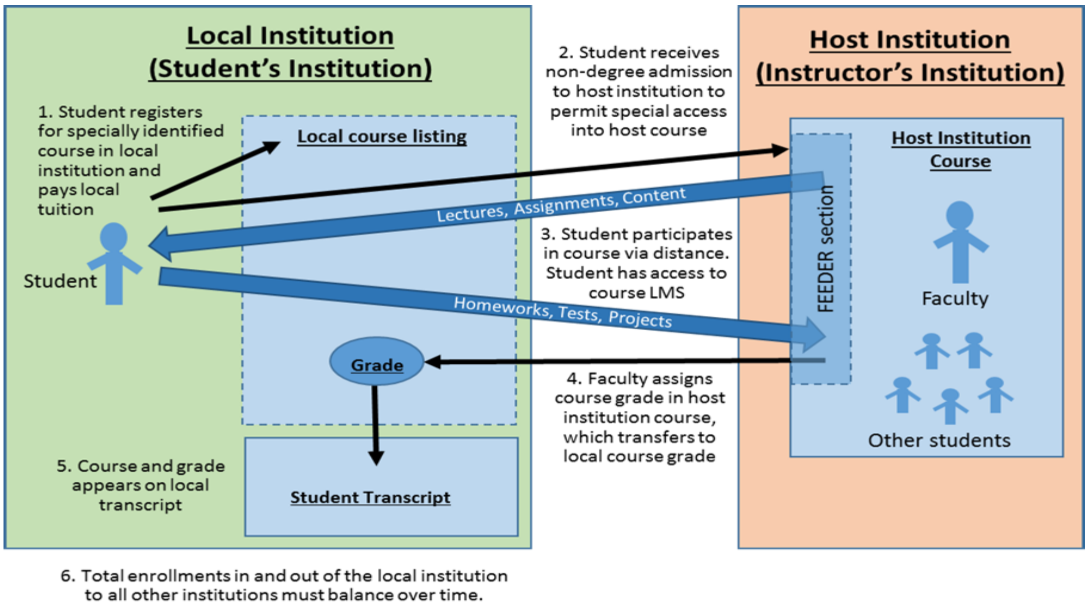

FIGURE 2. Operationalizing the multi-institution agreement to offer power and energy courses through the FEEDER consortium.

his/her local institution, and pays tuition to his/her local institution and any fees that apply.

2. In order to provide access to the host institution course materials (through its Learning Management System, or other methods), the student also enrolls at the host institution as a non-degree seeking student, and enrolls in a specially-designated section of the course for FEEDER students. No tuition is due to the host institution for enrollment in this specially-designated section.
3. The student participates in the course via distance learning, such as via video or on-line methods. The student has access to all assignments and content through the host's Learning Management System (LMS).
4. At the completion of the course, the faculty member at the host institution assigns a grade to the student. This grade then appears as the grade on the student's local course. The instructor is also to provide a portfolio of the student's course work to the local institution, and the local institution may retain this information for assessment and accreditation purposes.
5. The grade on the student's local course registration appears on the student's transcript at the local institution. The course thus applies towards the student's degree at the local institution.
6. The agreement is established as a reciprocal exchange of students in the FEEDER consortium. Thus, a participating FEEDER institution is to offer power-engineering related distance courses to which students from other participating institutions can register. Over a designated period, the number of students from the local institution registering for classes from other FEEDER institutions must balance the number of students from these other institutions registering for classes from the local institution. Thus, over a designated period, the student registrations from a university into and out of the network of other institutions balance each other so that tuition flows between institutions are not necessary.

The agreement also covers additional issues, such as ensuring that any course instructor for a distance SS-MD course must meet a common set of qualifications that satisfies all regional accreditation requirements. The different institutions have some freedom to implement the agreement within their own university processes. For example, courses may have specially designated course numbers or other designators to help identify whether it is for local students to register (and thus bearing tuition and appearing on the transcript) or is for distant students to register (and thus bearing no tuition).

It should be pointed out that the ability to deliver distance courses, such as SS-MD courses under FEEDER, requires approvals beyond the universities involved. In 2010, the US Department of Education ruled that state authorization is required for any institutions providing post-secondary educational offerings within that state [12]. Without such authorization, the delivery of an SS-MD course from one FEEDER institution to another FEEDER institution in another state would not be permitted. Fortunately, a State Authorization Reciprocity Agreement (SARA) was established that now covers 44 states, including many of the states of the FEEDER institutions [13], with the states of Kentucky and Pennsylvania joining only in November of 2016 [14]. However, as of the time of this writing, Florida was still not a member of SARA, although it is a member of a smaller 14 state agreement, SECRRA (Southern Regional Education Board

Electronic Regional Reciprocity Agreement) [15]. This limits the Florida FEEDER institutions from full participation in online SS-MD courses with institutions outside the SECRRA agreement.

The establishment of the multi-institution FEEDER course share agreement was non-trivial, as it required agreement of each institution and consideration of the processes such as admission, registration, billing, transcripts, etc. within each institution. The full implementation of the shared courses is also limited by state reciprocity agreements, but these are progressing. As noted before, the first SS-MD distance courses will be offered during the Spring 2017 semester.

V. EXPERIENCE PROGRAMS FOR MULTI-INSTITUTION INSTRUCTION SOURCE, SINGLE-SITE DELIVERY (MS-SD)

The final type of program delivery for the FEEDER consortium we consider is Multi-institution Instruction Source, Single-Site Delivery (MS-SD). These programs bring students from multiple institutions together for a concentrated learning experience. These are offered during the summer when there will be less conflict with scheduling across the different institutions, so we refer to these as FEEDER Summer Institutes.

The FEEDER Summer Institute programs were developed to provide students across the FEEDER consortium with opportunities for learning experiences that cannot be provided by distance methods alone. Specifically, these programs bring students from the participating institutions together for a concentrated educational program that includes visits or activities at industry sites, institutional labs, and national labs. These visits are supplemented with instruction by industry engineers or national lab personnel and by faculty from different FEEDER institutions. A recurring theme from student evaluation comments for these programs is the value of the exposure to industry (and national labs) and the ''real world'' applications of the material that they learn.

These Summer Institutes also give the students from various institutions an opportunity to interact with each other and with researchers and industry personnel from different organizations. This gives these students a variety of different perspectives on topics, and helps them create a community of collaborators and colleagues. This extends a student's community, and exposure, from his/her single institution to a much broader group of people, including students, faculty members, researchers, and industry personnel. On student evaluations, students recognize the diversity of speakers and interactions that they receive from these programs. One student's comments focused specifically on the student interaction: ''*I think that being able to spend time with other students and learn about their research areas has sparked opportunities to partner and grow together as we progress in our careers.*''

The FEEDER consortium to date has offered three different Summer Institutes. These are overviewed below.

- *University of Central Florida (UCF) Summer Institute (summer 2014)*: Students from six institutions were brought together at the University of Central Florida (UCF) campus for a week of workshops and visits. The program was structured around three independent one-day workshops, supplemented by a tour of a solar facility, two industry presentations, and one non-technical off-site visit for networking.
- *University of Kentucky (UK) Energy Experiences Program (summer 2015)*: Twenty one students from five institutions participated in a week of visits to ten energy sites over four states. These sites included generation for coal, natural gas, hydro, and nuclear, as well as a wind farm, solar farm, biogas producer, and a landfill gas generation site. The visits included an electric distribution cooperative, a military base micro-grid, a smart-grid demonstration site, and pumped storage facility. Students learn from engineers and operators at each site, and have supplementary online reading materials and assignments. UK's Power and Energy Institute (PEIK) has offered this Energy Experiences program as part of a three-credit-hour course annually since 2011 [16], but in 2015 opened the course to students from other FEEDER institutions.
  Comments on student evaluations from the 2015 course emphasized the value of seeing the sites directly, hearing directly from industry operators and engineers, and also the interaction among students from different institutions. Example student comments were: ''*... This should be a key course for Engineering. I could see it being a course that is highly sought after by students ... I also liked that students from other universities accompanied us and that we could share our experiences and interests.*'', ''*You can only learn so much from second-hand sources. Actually going to the facilities and witnessing the sheer scale of operations helped significantly in understanding the technologies utility companies utilize.*''
- *National Renewable Energy Laboratory (summer2016)*: Thirty students participated in a week of workshops and visits at the National Renewable Energy Laboratory (NREL) in Golden Colorado. Workshop sessions were taught by faculty from various FEEDER institutions, as well as by NREL staff. Students had a project on grid modeling and analysis software (using GridLab-D [17]) and a team project on comparative analysis of renewable resource opportunities for different states. Students visited the NREL labs and wind-farm. Students also had group sightseeing to regional natural sites, as well as other opportunities for group networking.
  For evaluating the 2016 program, students were asked about balance between different aspects of the program: technical lecture content, technical tours, projects, programming assignment, and non-technical (networking and sightseeing) content. Students requested more time

on technical tours, programming/modeling project, and non-technical content. Regarding the amount of time spent on technical lectures and the comparative analysis group project, there was a wider variation in responses, but still most felt the balance of time was correct. On the technical lectures, the negative comments indicated that some students felt that there was too much content coverage without sufficient time to think about it or to work through it, and felt that the technical lecture content should be paced differently with more time for student engagement with the class and material. Such comments are not surprising, and indicate a challenge when conducting intensive, condensed learning experiences such as these summer institutes.

Students involved in the summer institute programs in 2014 and 2016 did not receive course credit for their involvement. Students involved in the summer institute in 2015 had the option to receive three credit hours with supplementary content and assignments, as the program was built on an existing course offering at the University of Kentucky.

The summer institute programs have been rated as very worthwhile by the students, as the programs provide students with cross-institutional and industrial interactions as well as on-site experiences that would not be possible in a course at a single institution or even a distance or on-line course across multiple institutions. However, the negatives or challenges of these types of programs are evident. First, the structure of these courses by their nature limit the number of students that are able to participate. Visits to industry sites and national lab sites are very beneficial to the students, as are industry presentations, but these take time and effort from the industry and lab personnel. For the UK Summer Experiences program, one visit site has repeatedly indicated that they only accommodate a couple of student tours per year, and so any expansion of the program to more students would require finding an alternative industry site. Also, it should be noted that many industrial sites have limited personnel to conduct tours, and facilities are not built to accommodate many visitors at a time. This limitation of access and personnel at individual sites could be overcome by offering programs distributed geographically, when possible. Thus, the burdens of involvement of individual companies (or labs or institutions) could be alleviated by involving others in different geographical areas instead.

A second issue with these summer programs is the expense associated with student travel and lodging during the institutes. Students need to travel to the site of the summer institute, which in most cases is long distance. For lodging, during the 2014 and 2016 programs, students stayed in residence halls of area universities. For the 2015 program, students stayed in hotels due to the extensive travel. Financial support for the programs are provided through grants, institutional support funds, and (in the case of 2015) tuition return funds.

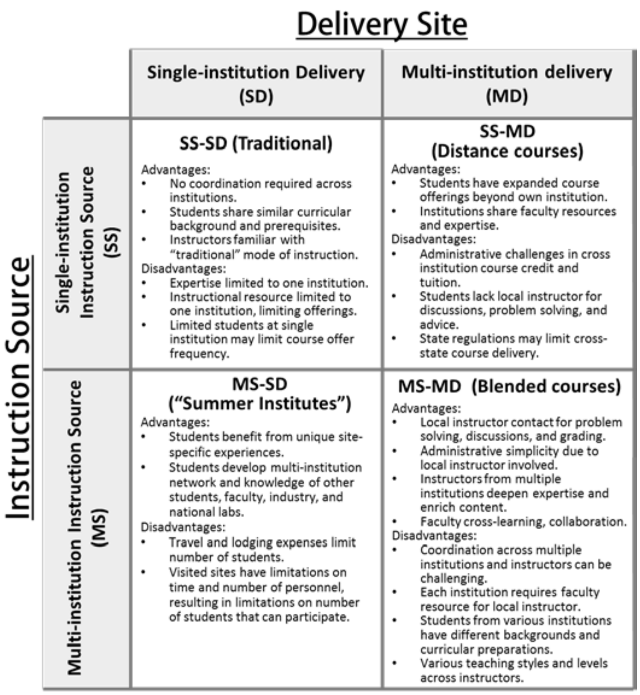

FIGURE 3. Summary of advantages and disadvantages of different multi-institutional collaboration approaches.

VI. CONCLUSIONS AND IMPLICATIONS

The FEEDER consortium of universities was developed through support of the US Department of Energy in order to provide students from across the consortium with expanded power-engineering education opportunities. This paper has outlined three approaches in which this is being accomplished, through three different models of multi-institution collaboration. The paper outlined the experiences of the FEEDER Consortium in implementing these three models, and overviewed positive and negative aspects of each approach. Figure 3 summarizes these. The curriculum was driven with input from external partners, and one of the models (MS-SD) required active involvement of industry and lab partners to provide student educational experiences. It should be noted that even the SS-SD traditional classroom delivery, without direct collaboration, benefited indirectly from the collaboration of the consortia, as shared content and collaborative discussions within the consortia have influenced the content in even traditional single-instructor single-institution courses.

Although this paper has discussed multi-institution collaboration in the context of power engineering education, the discussed methods are not limited to the power engineering field. It is the view of the authors of this paper that more such multi-institution collaboration will occur in the future. Current technology facilitates distance collaboration and distance teaching, and it is logical to use this distance ability to offer students more educational opportunities than they would have within only their own institution.

These collaborations are not necessarily simple, as they require both faculty coordination and institutional (and in some cases state-level) collaboration. These collaborations not only benefit the students with more educational course options, but also provide the involved faculty with opportunity for expanding collaboration with other faculty beyond the classroom. Such collaborations are also conducive to engagements with national laboratories and industry.

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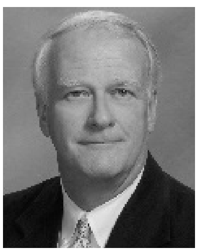

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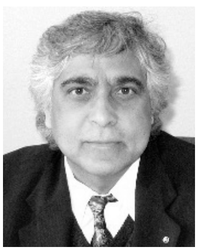

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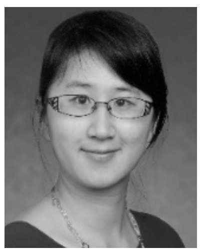

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